FROEHLICH & LOHMAN

Transverse Tests of I-Beams

Civil Engineering

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TRANSVERSE TESTS OF I-BEAMS

BY

MILTON HECKSCHER FROEHLICH
AND
FREDERICK CHARLES LOHMAN

THESIS

FOR THE

DEGREE OF

BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1911

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UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING

June 1, 1911.

This is to certify that the thesis prepared in the Department of Theoretical and Applied Mechanics by FREDERICK CHARLES LOHMAN and MILTON HECKSCHER FROELICH entitled Transverse Tests of I-Beams is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

H. F. Moore
Instructor in Charge.

Approved:

Ira O. Baker
Professor of Civil Engineering.

197609

DLC

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INTRODUCTION.

In 1910 it was thought advisable to run a series of tests on I beams for the purpose of investigating the formulas for the elastic limit and ultimate strength of beams under conditions common in practice. As a result, data were compiled by Messrs. Deuchler and Weston on various lengths and sizes of I beams. As a continuation of these tests, and, in order to more fully complete the available data, the present thesis was undertaken.

Previous to these tests, very little had been done in an experimental way along this line; but, as a result of the tests of Professor Marburg of the University of Pennsylvania and others, it was decided to undertake these theses to determine the effect of lateral restraint upon the ultimate strength and elastic limit of beams, the variation of the maximum fiber stress with the span, and the relative yield points of the material in tension and compression.

THEORY AND AVAILABLE DATA.

The number of experiments that have been performed on steel I beams, as well as the amount of mathematical discussion on the subject, is very small. The available material may be divided into two classes:- (a) hand-book data; (b) experimental data. The former is valuable in that it furnishes a means of obtaining the permissible loads that can be used. The experimental data, with the exception of the results obtained by Messrs. Deuchler and Weston in 1910, is of very little value as a means of comparing results.

MARBURG'S TESTS. One of the most interesting, and probably the most extensive series of tests was conducted by Professor Marburg of the University of Pennsylvania. The purpose of these tests was to determine the relative strengths of the Bethlehem special sections and the standard I-beams in order to determine the relative economy of metal. The Bethlehem beams have a wider flange and thinner web, which gives a lower weight for corresponding section moduli. In these tests, Professor Marburg found that the standard beams failed almost uniformly by sidewise buckling, while the Bethlehem sections failed by twisting of the web, the beam taking the form of a flat letter "S", the flange remaining straight. These beams were tested without sidewise restraint; both the Bethlehem and standard sections showed a maximum stress considerably less than the theoretical value.

Another interesting feature of these tests was the variation in strength of the various specimens taken from the roots of the flanges, the web near the flange, and the outer edge of the flange. Specimens taken from the root of the flange showed a considerably lower elastic limit than the other specimens. Professor Marburg explained this variation as due to the difference in the amount of

rolling received by the different portions of the beam, the parts receiving the least rolling being the weakest.

Professor Marburg also found that the modulus of rupture for both the standard and Bethlehem sections loaded at the quarter points was much less than for beams loaded at the middle.

HANCOCK'S TESTS. About a year after Professor Marburg conducted his experiments at the University of Pennsylvania, Mr. E. L. Hancock performed a number of experiments on specimens taken from different portions of I beams to determine their relative strengths and causes for their variation. The experiments were conducted very carefully; microscopic examinations were made to determine the texture of the fibers in each specimen. In drawing his conclusions, Mr. Hancock virtually corroborated Professor Marburg's results as to variation of strength of material. Mr. Hancock found that the texture and strength of the specimens varies with the amount of working the metal receives.

MICHELL'S ANALYSIS.- In the "Philosophical Magazine" of September 1899, Mr. A. G. M. Michell gives a discussion on the theory on the failure of beams based on the theory that beams fail more because of lack of torsional rigidity than flexural rigidity. The results of his formulas can not be compared with those of this thesis, because the factor representing the torsional rigidity is not available.

HESS' ANALYSIS. Mr. H. D. Hess, in a paper presented before the Engineers Club of Philadelphia, developed a formula giving the variation in the length of beams with their length. This formula is based on Rankine's column formula, the force in the compression flange being assumed to act along the axis of the flange. From the fact that this force varies from zero at the ends to a maximum at

the center, a length of span is deduced such that the combination of the buckling effect due to this length and the stress occurring at its end gives a maximum fiber stress. This formula is developed for a uniform load. In the thesis of Messrs. Deuchler and Weston the constant of the formula has been deduced for third-point load- to make it applicable to their tests.

In addition to the articles given above, there is a discussion of doubtful reliability by A. E. Guy based on an elaborate series of experiments on wooden beams; there is also the thesis of W. E. Deuchler and F. W. Weston, of which the present thesis is a continuation.

LITERATURE.

MARBURG:- "Proceedings of the American Society for Testing Materials", 1909, vol. 9, page 378.

HESS:- "Proceedings of the Engineers Club of Philadelphia" April 1909, vol. 26, page 106.

MICHELL:-"Philosophical Magazine", Sept. 1899, vol. 48, page 298.

GUY:- "Flexure of Beams" (Van Nostrand).

HANCOCK:-"Engineering Record", July 9, 1910, page 48.

BACH:- "Zeitschrift der ver. Ingenieure", March 1910, page 382.

HUDSON:- "Engineering News", Dec. 9, 1910, vol. 62, page 645.

MATERIALS, APPARATUS AND MANIPULATION.

In all, fourteen tests were made on standard I beams purchased in the open market and rolled by the Illinois Steel Company. All of these were 8 in. 18 lb. I beams. The lengths, sections and other important data concerning the I beams are found in Table 1.

The beams were tested under three conditions;- with and without lateral support, and with the ends restrained laterally, In tests 1, 5, 10, 11, and 12 the two 8 in. 18 lb. beams were fastened together on the compression side by batten plates 4 in. x 3-8 in. x 1 ft. spaced approximately one foot center to center, as shown in Figure 8. In tests 7, 9, and 14, single beams with ends fixed as as shown in Figures 4 and 9 were used. In the remaining tests, the beams were left free to move in any direction.

In the above tests, the load was applied at the third, sixth and middle points of the beam, and was distributed to the proper points of application by means of a short beam of sufficient depth and section, bearing on rollers and plates. The beams were supported at the ends by ordinary rocking supporting blocks, spherical blocks, and rollers with plates. The load was applied to the loading beam by means of a spherical block and seat at the center, as shown in Figure 8. In the majority of the tests, an Olsen 200,000-pound beam-testing machine with a long table was used.

In performing the tests, two measurements were taken:- the deformation of the upper and lower flanges for a guage length of 10 inches taken at the middle of the beam, and the deflection of the beam at the center. In observing the deformation of the upper and lower flanges, an extensometer as illustrated in Figures 10 and 11 was used. Two castings, of shape shown in Figure 1, were fastened 10 inches apart, to each side of both the upper and lower flanges.

These furnished a means of keeping a standard guage length. The castings were fitted with spherical balls; and the change of dis- between the balls of a pair of clamps was measured with a machinist's test guage suitably mounted. In observing the deflection at the center of the beam, three devices were used:- wire-wound dials, extensometers and a graduated scale. Several methods of supporting the wound dial were devised, but none proved satisfactory because of the interference of the necessary supports with the manipulation of the extensometer used in taking the flange readings. The extensometer used was of special design, and had been used in previous work. It consisted of the ordinary dial, with two arms of rather short lengths, the ends of which were hollowed so as to give a conical bearing. In manipulating the extensometer, it was placed between two spherical balls, one-half inch in diameter, arranged one above the other as shown in Figure 5. These balls furnished a bearing for the ends of the extensometer and prevented errors due to the centering of the instrument. This device was used only in test 5. For tests 7, 10, 13 and 14, a graduated scale was fastened to the beam between the flanges. A wire was then stretched from one end of the beam to the other, and passing through the center of the beam directly over the supports. A heavy elastic was attached to one end of the wire to keep it taut. This proved to be the most satisfactory though least sensitive of any of the devices used. Figures 5, 6, 7, 10, and 11 show the kinds of devices used and the method of application.

One thousand pounds was taken as a zero loading and all zero readings were taken at that load. The load was applied to the beam by increments, and when removed, was always brought back to the zero loading. When, after several increments which caused appreciable sets had been applied, all instruments were removed and the beams

tested to failure. After each reading, the extensometer for flange measurements was compared with a standard previously established so as to prevent errors due to the instrument. All flange readings were taken to the nearest ten-thousandth of an inch.

After the beams were tested, specimens for tension and compression tests were cut from the least stressed portions of the web and flanges, as shown in Figure 2. Only the specimens taken from the flanges were tested, the remaining specimens being reserved for a future date. In the tension tests, the yield point was noted by the drop of the beam and by means of dividers. In the compression tests, the ends were fixed as shown in Figure 12 and the yield point observed by means of the autographic attachment. The results of the tests on the above specimens are shown in Table 4

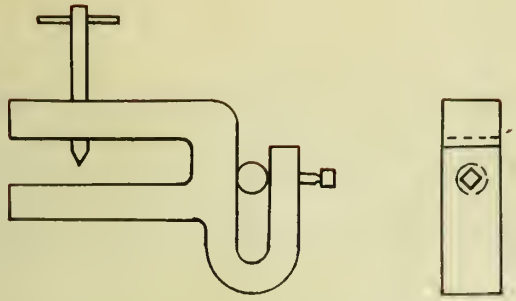


Fig. 1.

Fig. 2.

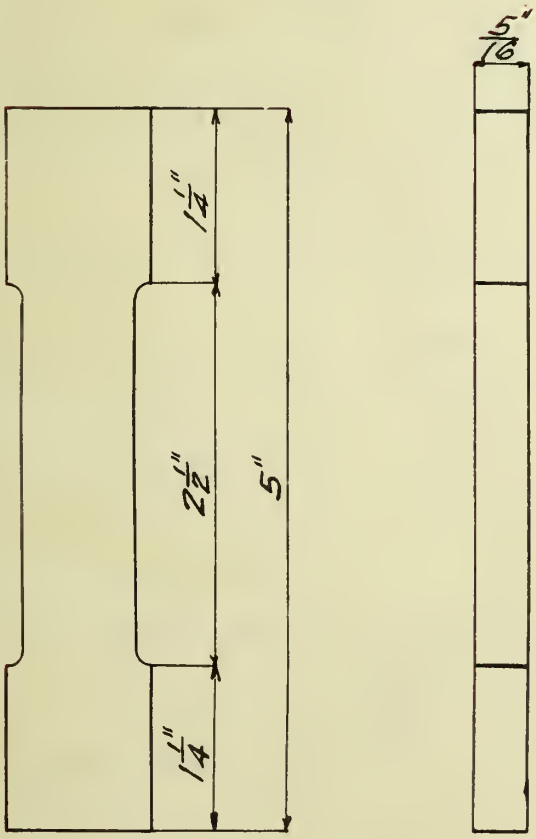


Fig. 3.

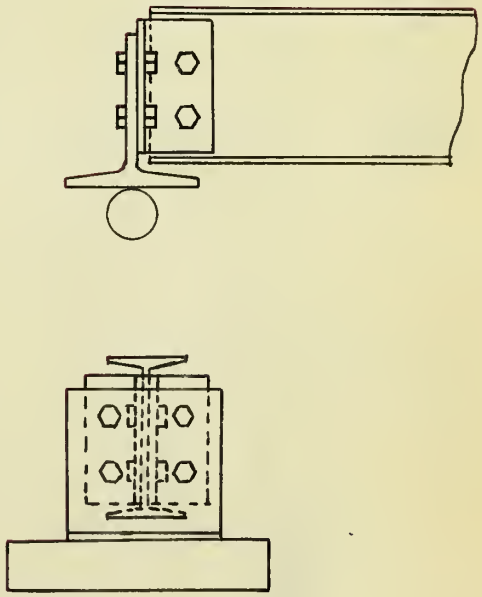


Fig. 4.

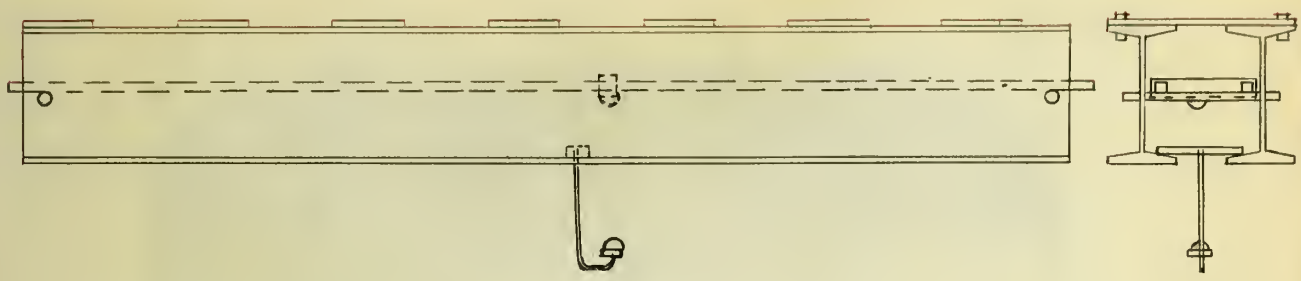


Fig. 5.

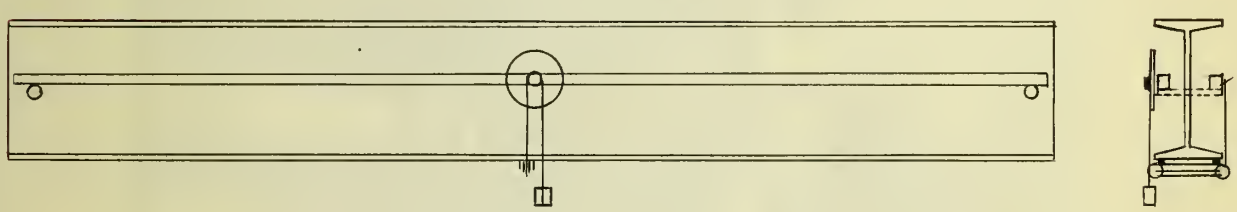


Fig. 6.

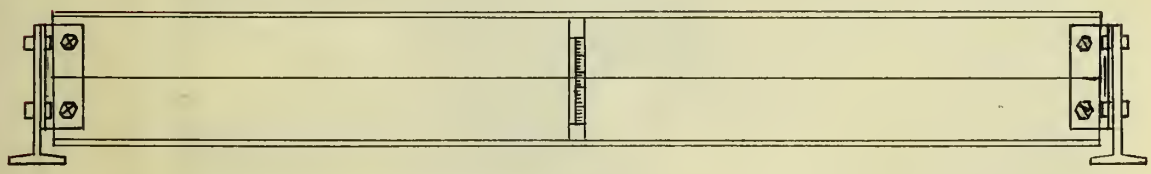


Fig. 7.

Fig. 8.

Fig. 9.

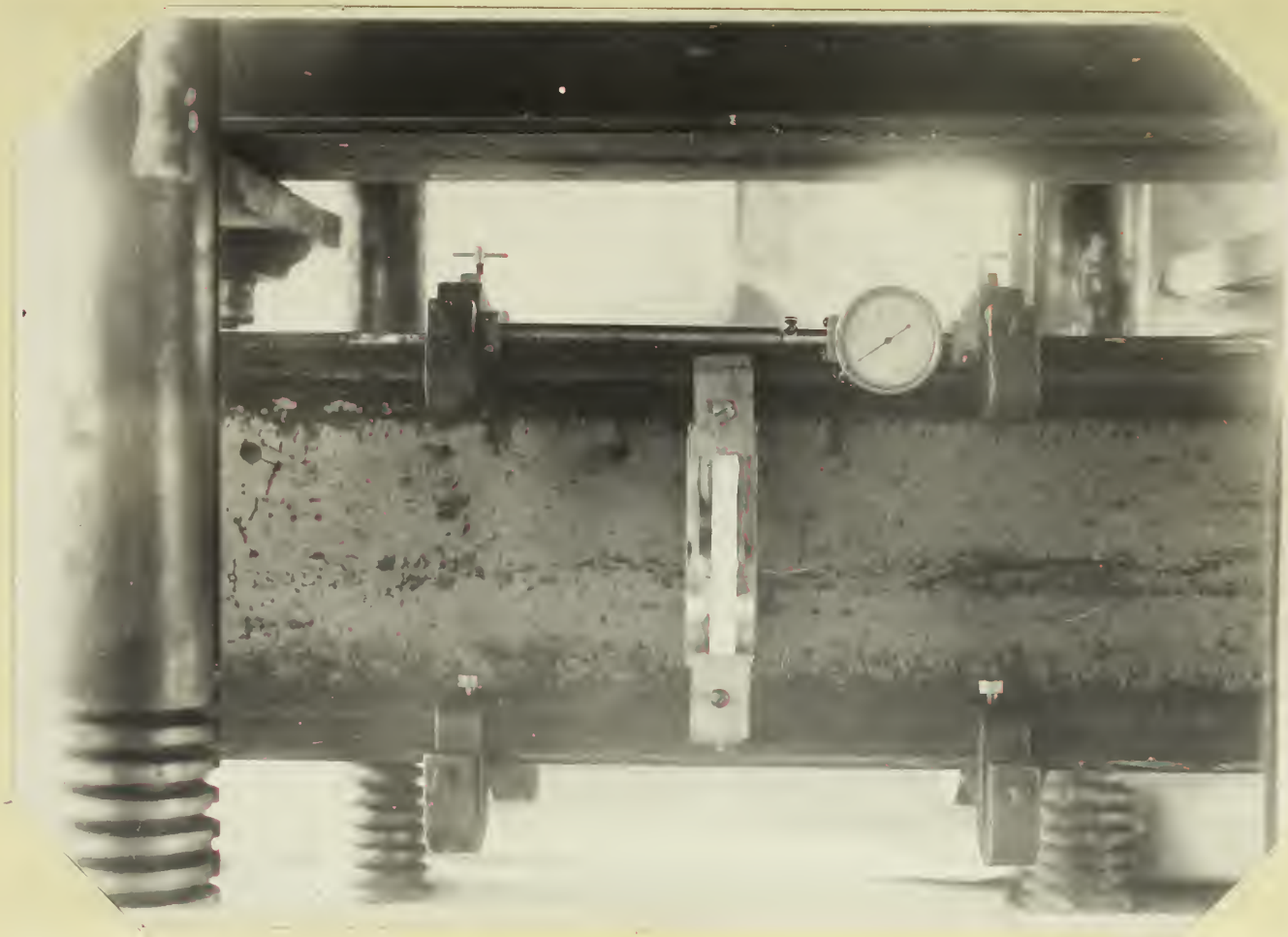


Fig. 10.

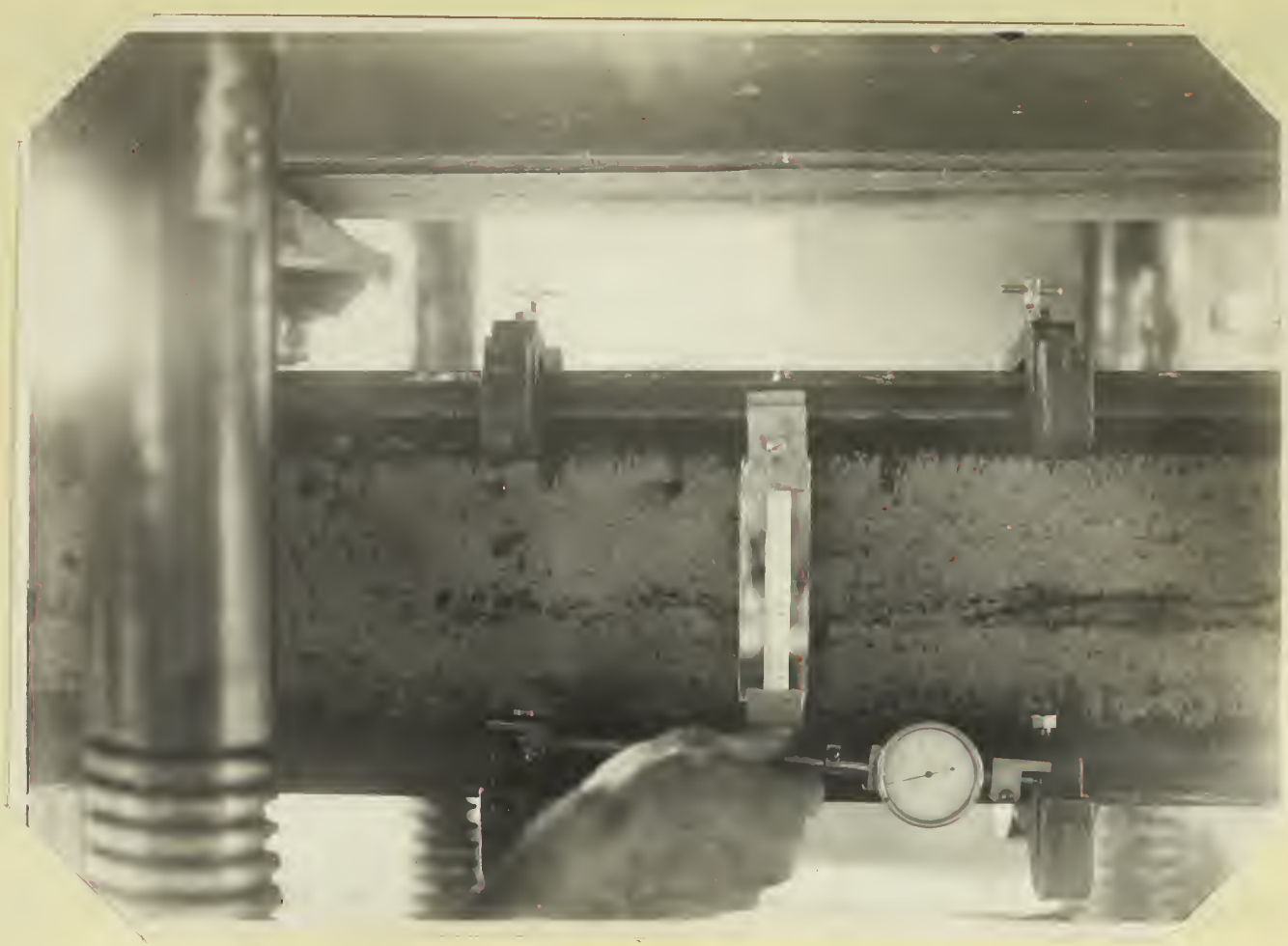


Fig 11.

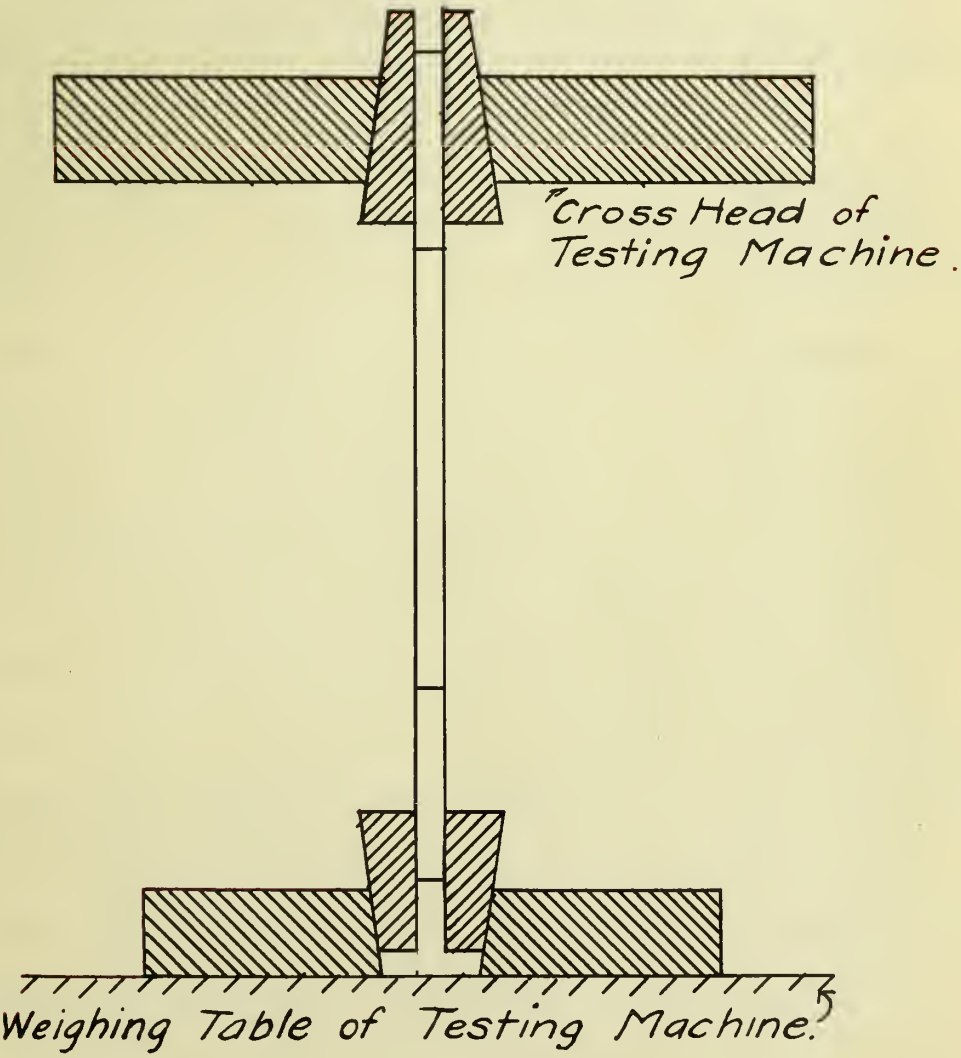


Fig. 12.
Method of Testing Specimens in Compression.

SAMPLE LOG SHEET.

Test No. 4 Feb. 11, 1911.

Length of beam 10'- 0" (distance between supports).

Load lb.	Extensometer Readings				Deflections	Standard	Remarks
	North		South				
	Upper	Lower	Upper	Lower			
5000	79.0	75.1	4,7	37.6	0	0	
10950	81.1	74.0	6.0	36.0	55.0	0	
5000	79.4	75.2	4.9	37.1	0	0	600,000 lb. machine used.
15000	82.5	73.7	7.0	35.0	51.5	0	
5000	79.8	75.5	5.1	37.2	4.0	0	Speed 0".4 per
21050	84.4	72.1	8.0	33.5	85.0	0	min. up to
5000	79.8	75.5	5.2	37.2	3.5	0	45,000 lb.;
25700	85.3	71.0	8.4	32.0	106.5	0	then 1-20 in.
5000	79.5	75.5	5.0	36.0	3.5	0	per min. to
29850	87.0	70.2	9.5	30.0	129.0	0	failure.
5000	80.0	75.5	5.3	35.8	7.5	0	Beam loaded
36400	88.7	68.0	10.0	28.0	171.0	0	at sixth pts.
5000	80.1	75.0	5.0	34.8	12.5	0	Failed by
37800	89.0	68.0	10.0	26.8	183.0	0	sidewise buck-
5000	81.1	75.1	5.0	33.8	17.5	0	ling.
41920	91.3	67.0	10.3	24.7	212.5	0	
5000	81.5	75.0	4.9	32.8	21.5	0	Test pieces
44200	93.1	66.5	10.0	22.9	221.0	0	marked "4".
5000	85.9	75.0	4.9	31.1	29.0	0	
47660							Maximum.

TABLE I.

SCHEDULE OF TESTS ON I-BEAMS.

Test No.	Section of Beam	Length of Span, Ft.	Conditions of Lateral Support.	Condition of Ends	Point of Application of Load.	Ultimate Load, Lb.	Method of Failure.
1	8 in. 18 lb.	10'-0"	2 Beams laced	Free	Third Points	50,170	Bending
2	8 in. 18 lb.	10'-0"	None	Free	Middle.	17,120	Buckling
3	8 in. 18 lb.	10'-0"	None	Free	Middle	17,800	Bending
4	8 in. 18 lb.	10'-0"	None	Free	Sixth Points.	47,660	Buckling
5	8 in. 18 lb.	10'-0"	2 Beams laced	Free	Third Points.	52,000	Bending
6	8 in. 18 lb.	10'-0"	None	Free	Sixth Points.	42,000	Buckling
7	8 in. 18 lb.	20'-0"	None	Fixed	Third Points	10,360	Buckling
9	8 in. 18 lb.	5'-0"	None	Fixed	Third Points.	50,030	Buckling
10	8 in. 18 lb.	20'-0"	2 Beams laced	Free	Third Points	25,920	Bending
11	8 in. 18 lb.	5'-0"	2 Beams laced	Free	Third Points	118,000	Bending
12	8 in. 18 lb.	5'-0"	2 Beams laced	Free	Third Points	118,000	Bending
13	8 in. 18 lb.	10'-0"	None	Free	Third Points.	24,000	Buckling
14	8 in. 18 lb.	10'-1 1/8"	None	Fixed	Third Points	23,940	Buckling

TABLE II.

EXTREME FIBER STRESSES AT ELASTIC LIMIT AND ULTIMATE.

Test No.	Span, Ft.	Condition of Ends of Beam.	Fiber Stress, lb. per sq. in. at Elastic Limit, Johnson's Method as found from Load Deflection Curves		Average Compression Curves		Worst Compression Curves		Ultimate Fiber Stress, lb. per sq. in. $S = \frac{Mc}{I}$.	
			Actual	Corrected	Actual	Corrected	Actual	Corrected	Actual	Corrected.
1	10'-0"	Free	28,150	33000	28,100	33,000	27,700	32,500	35,350	41,400
2	10'-0"	Free	31,800	40,600	26,400	33,700	25,800	32,950	36,580	46,700
3	10'-0"	Free	34,200	39,950	31,000	36,100	31,600	36,850	37,600	43,800
4	10'-0"	Free	27,600	31,800	29,000	33,450	27,600	31,800	32,870	37,900
5	10'-0"	Free	24,750	27,900	24,000	26,750	28,200	31400	36,600	40,800
6	10'-0"	Free	21,400	27,000	10500	13,500	—		29,600	35,600
7	20'-0"	Fixed	23,800	28,900	23,600	28,450	20,000	24,150	29,220	36,300
9	5'-0"	Fixed			26,100	31,500	24,700	29,800	35,200	42,500
10	20'-0"	Free	26,100	26,500	27,000	28450	27,500	29,000	36,450	38,500
11	5'-0"	Free			24,000	25,300	21,450	22,650	41,500	43,800
12	5'-0"	Free	27,600	29,100	23,600	24,900	27,500	29,000	41,500	43,750
13	10'-0"	Free	26,600	29,350	28,100	31,000	24,000	26,450	33,800	37,300
14	10'-1 1/8"	Fixed	24,200	28,700	28,400	33,700	24,500	29,100	34,000	40,300

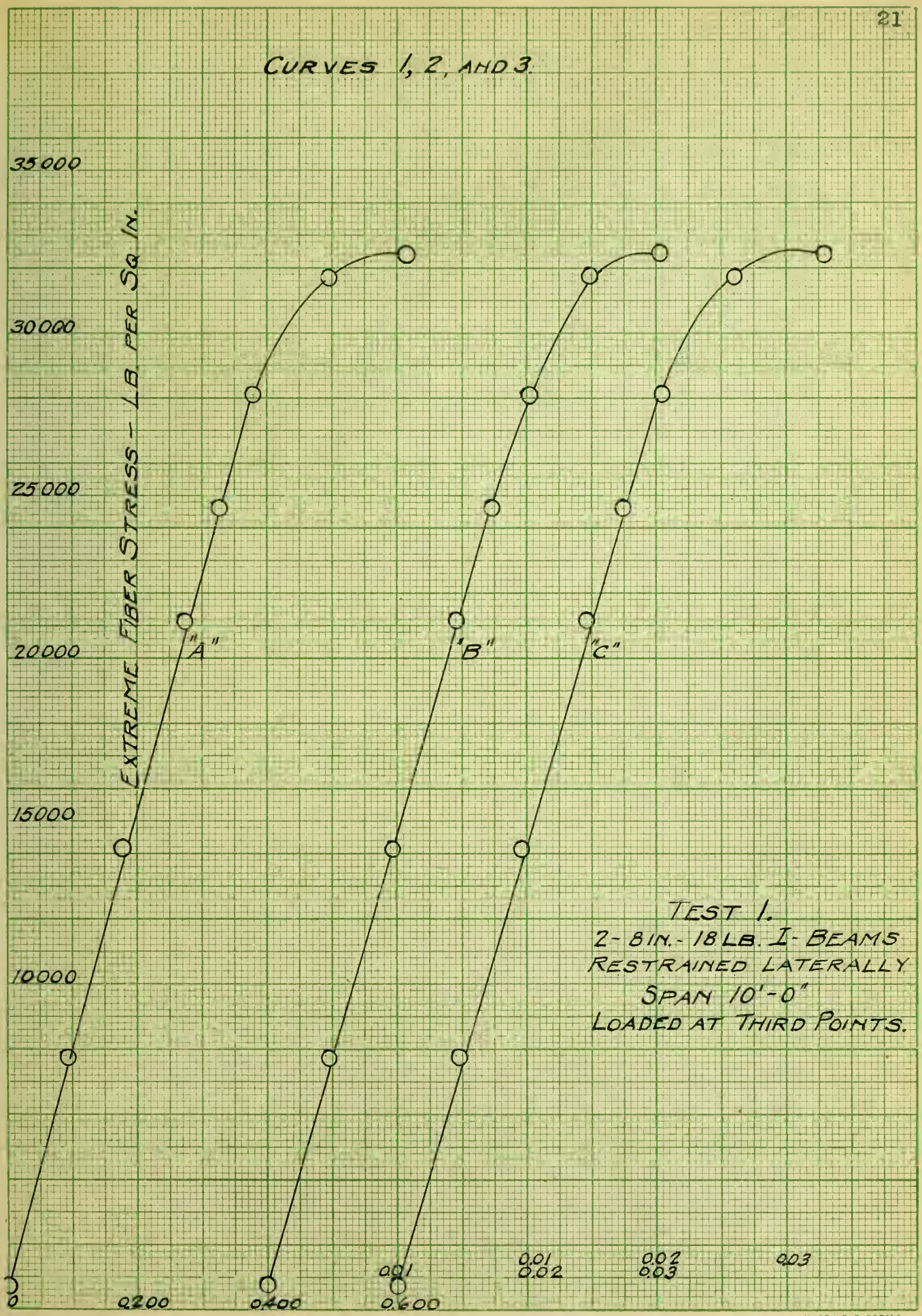
Note:- Corrected values are referred to a yield point of 40,000 lb. per sq. in. in tension for the material.

CURVES 1 to 38 INCLUSIVE.

Note:- All curves marked "A" are load-deflection curves.

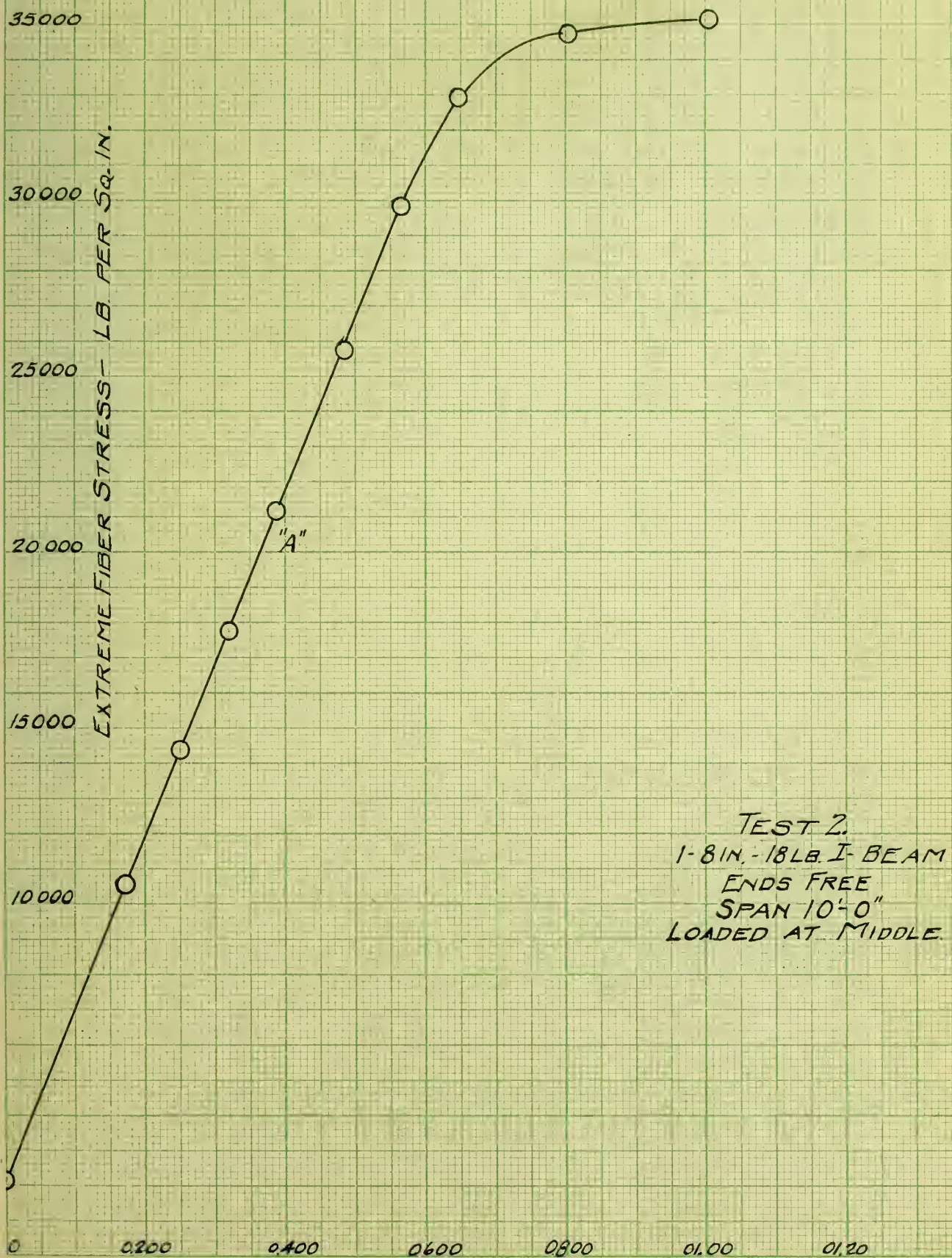
All curves marked "B" represent the average deformations of the compression flanges of the I beams.

All curves marked "C" represent the deformations of the compression flanges of the beams which showed the greatest deformation.



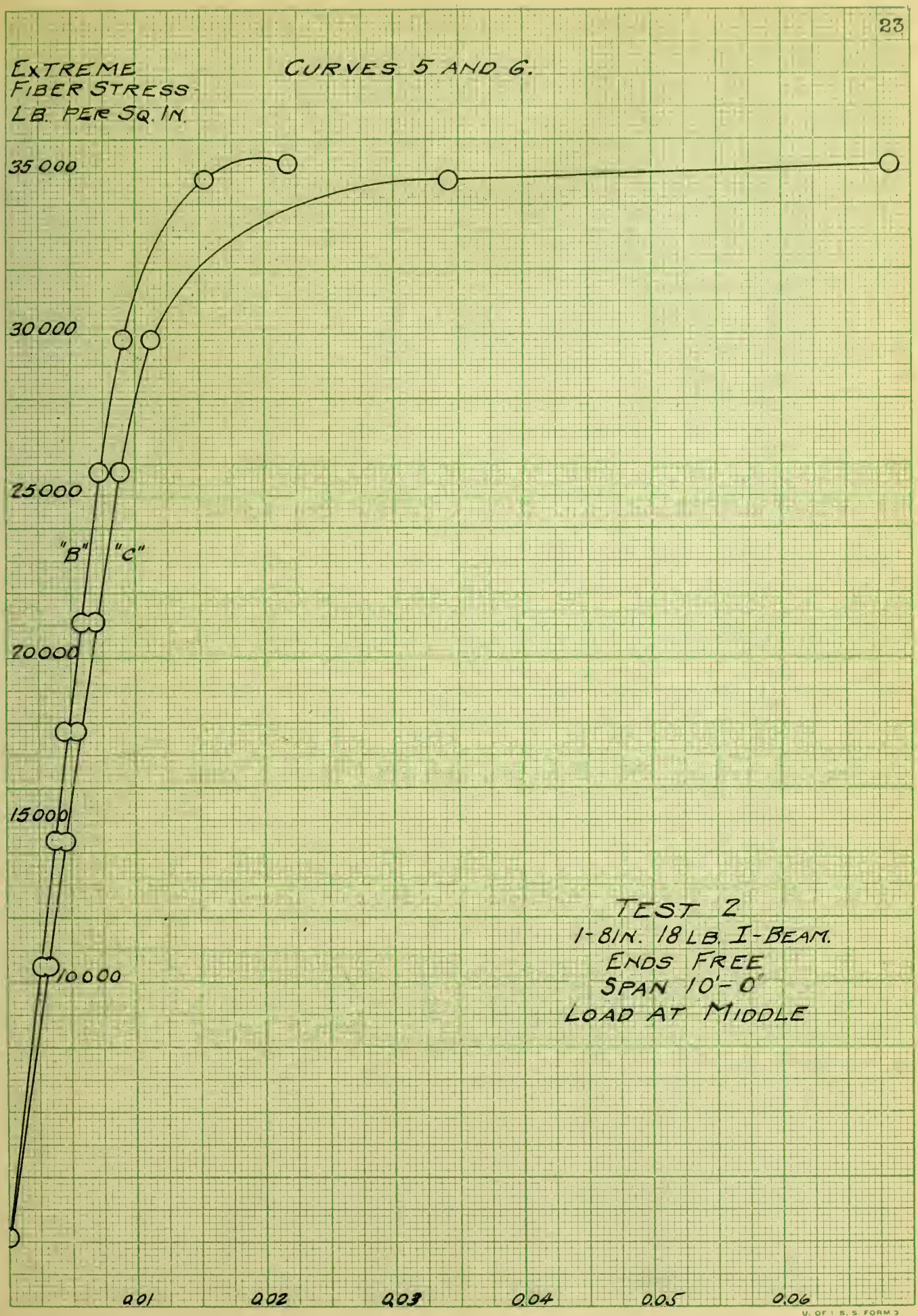
U. OF I. S. S. FORM 3

CURVE 4.



TEST 2.
1-8 IN. - 18 LB. I-BEAM
ENDS FREE
SPAN 10'-0"
LOADED AT MIDDLE.

U. OF I. S. S. FORM 3



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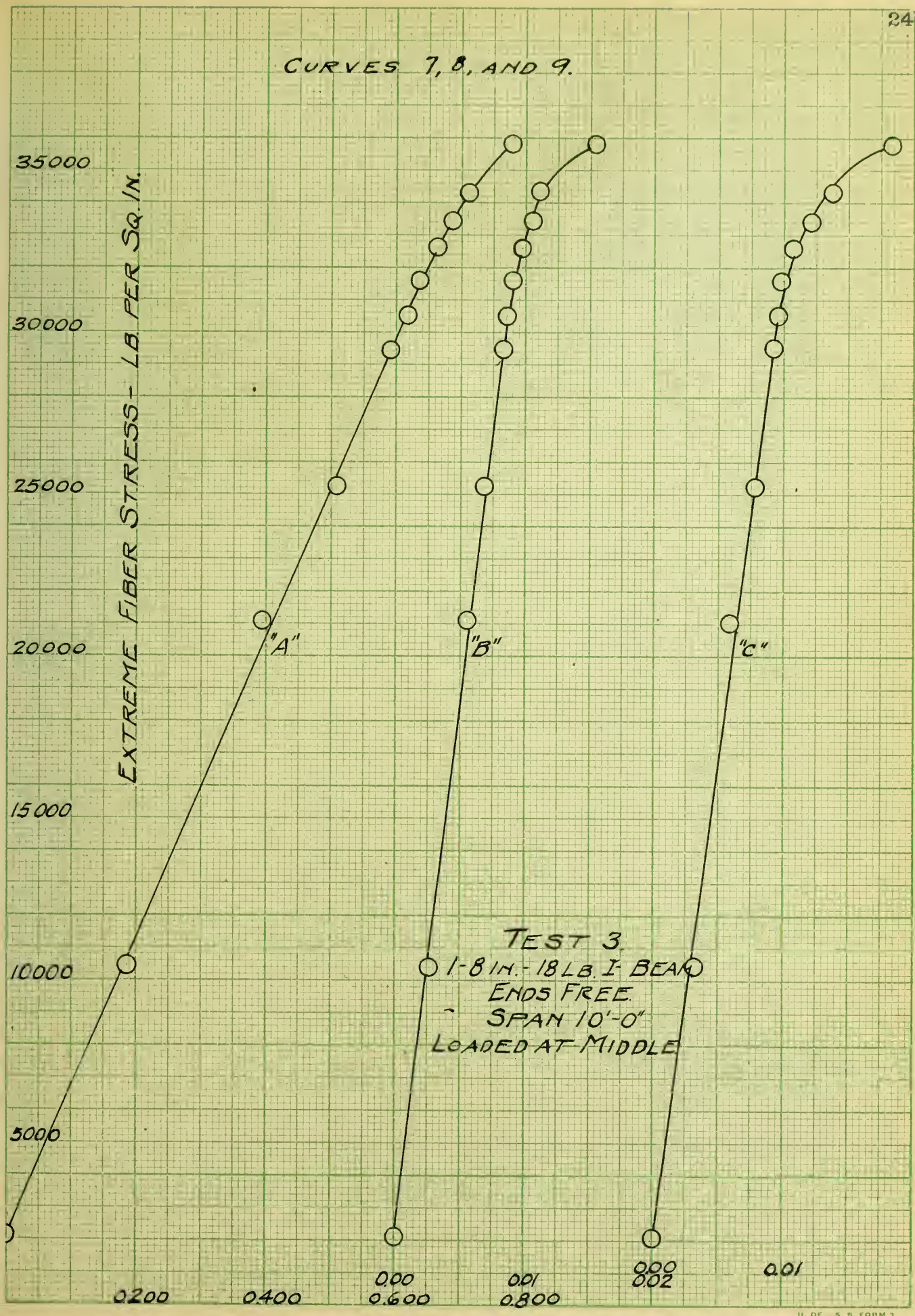
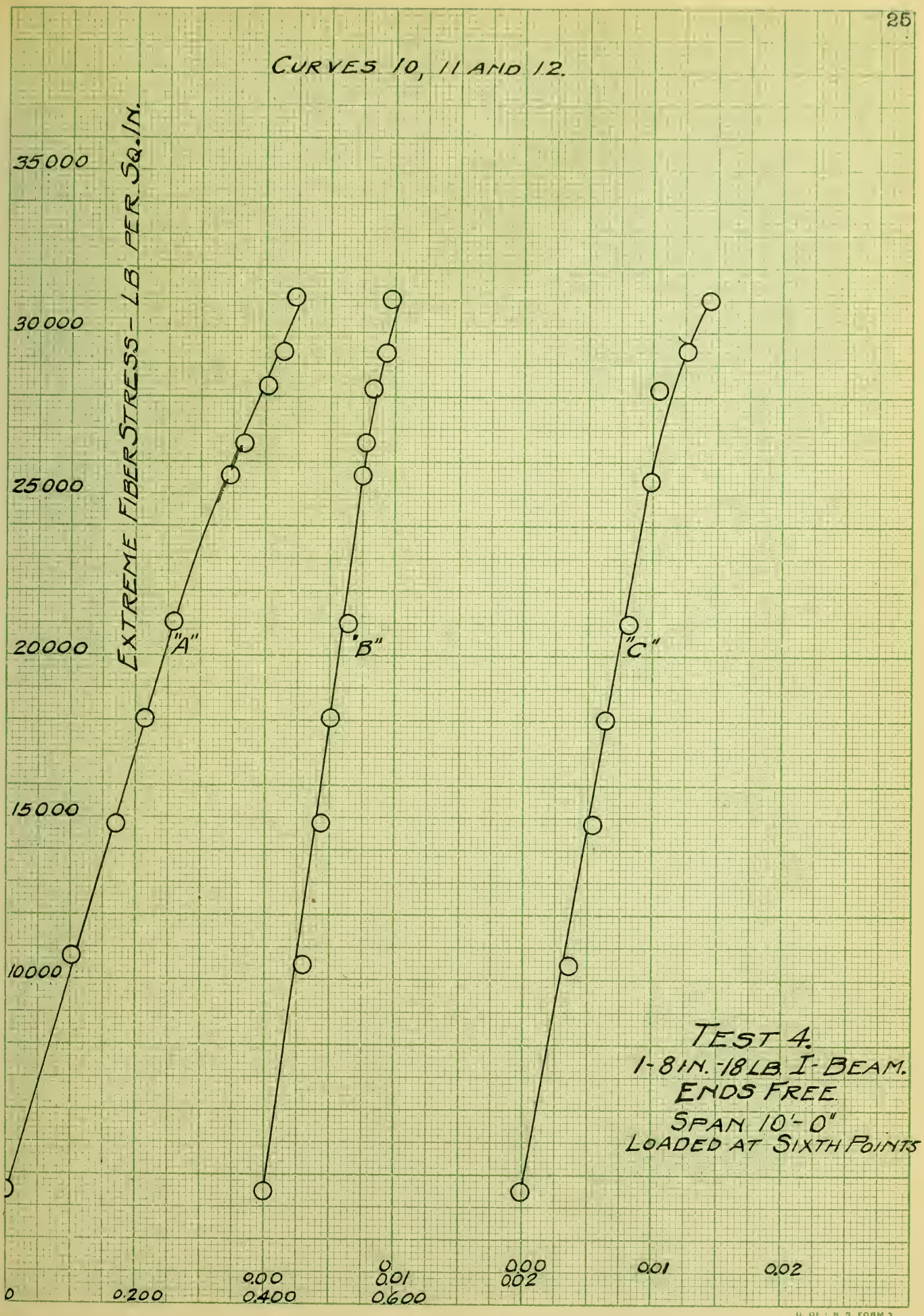
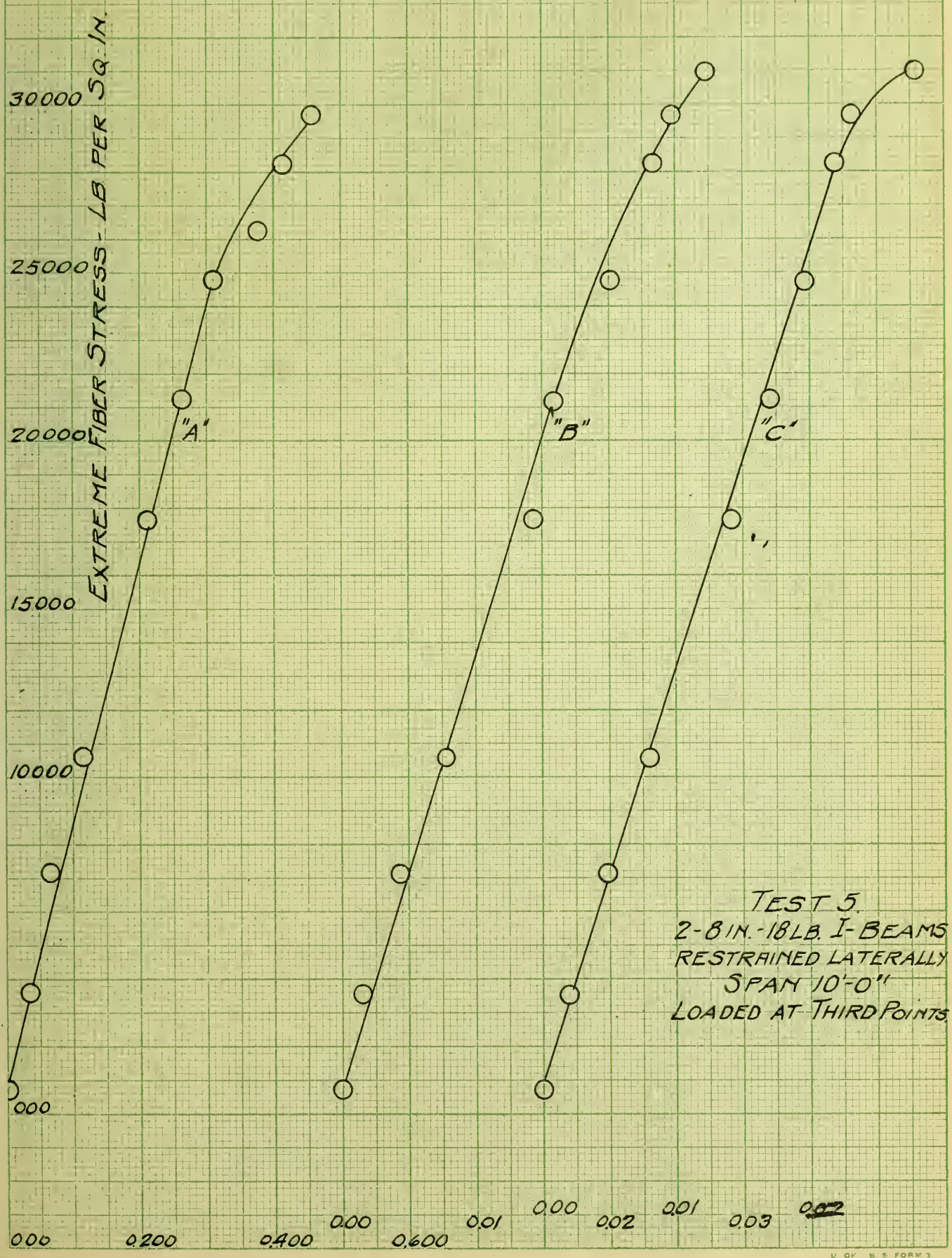

CURVES 7, 8, AND 9.
EXTREME FIBER STRESS - LB. PER SQ. IN.
35000
30000
25000
20000
15000
10000
5000
"A"
"B"
"C"
TEST 3.
1-8 IN. - 18 LB. I- BEAM
ENDS FREE
SPAN 10'-0"
LOADED AT MIDDLE
0.200
0.400
0.00
0.600
0.01
0.800
0.00
0.02
0.01

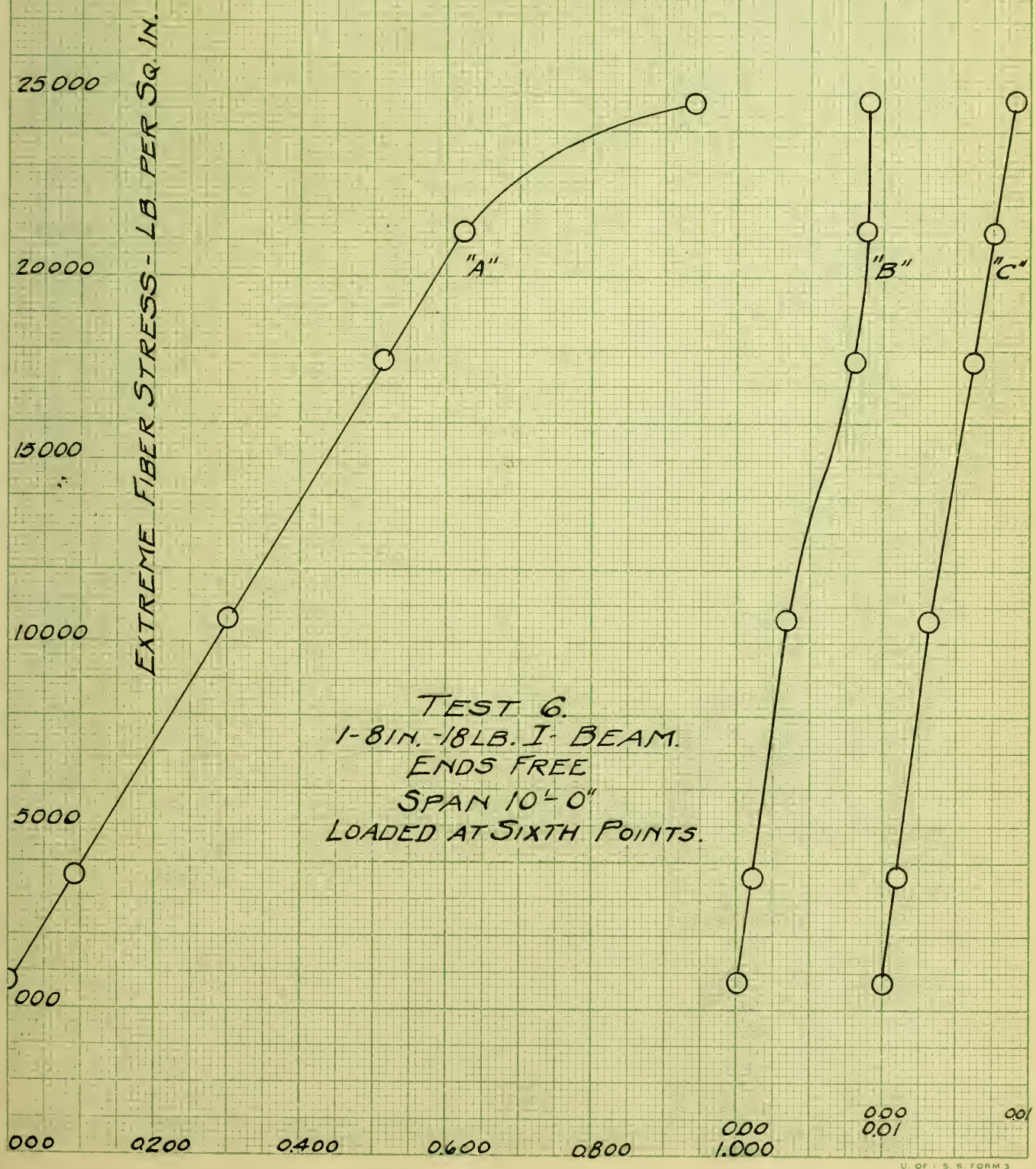
U. OF S. S. FORM 3


CURVES 10, 11 AND 12.
EXTREME FIBER STRESS - LB. PER SQ. IN.
35000
30000
25000
20000
15000
10000
"A"
"B"
"C"
TEST 4.
1-8 IN.-18 LB. I-BEAM.
ENDS FREE.
SPAN 10'-0"
LOADED AT SIXTH POINTS
0
0.200
0.00
0.400
0
0.01
0.600
0.00
0.02
0.01
0.02
U. OF I. S. 3. FORM 3

CURVES 13, 14 AND 15.



CURVES 16, 17 AND 18.



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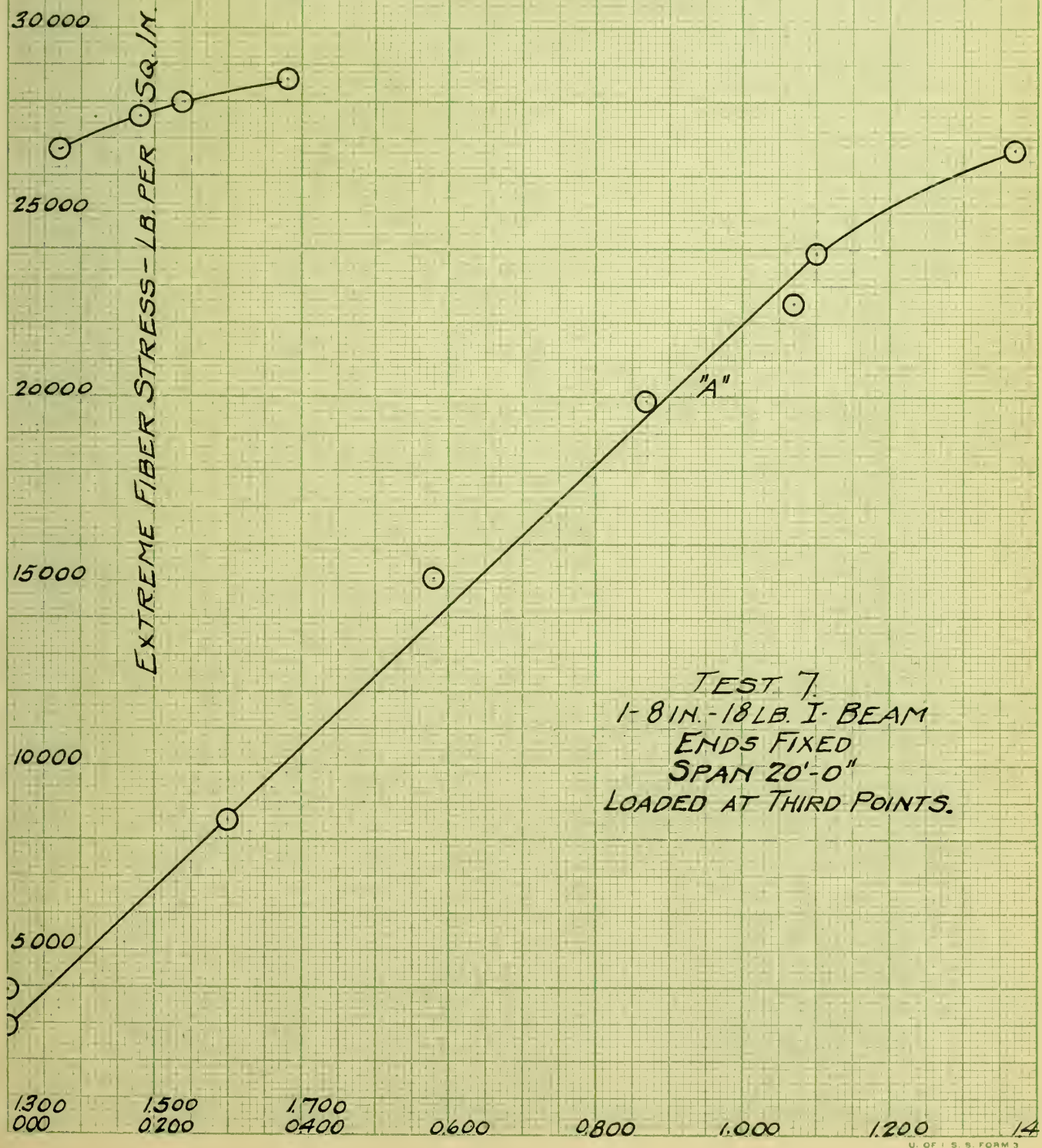
CURVES 19.



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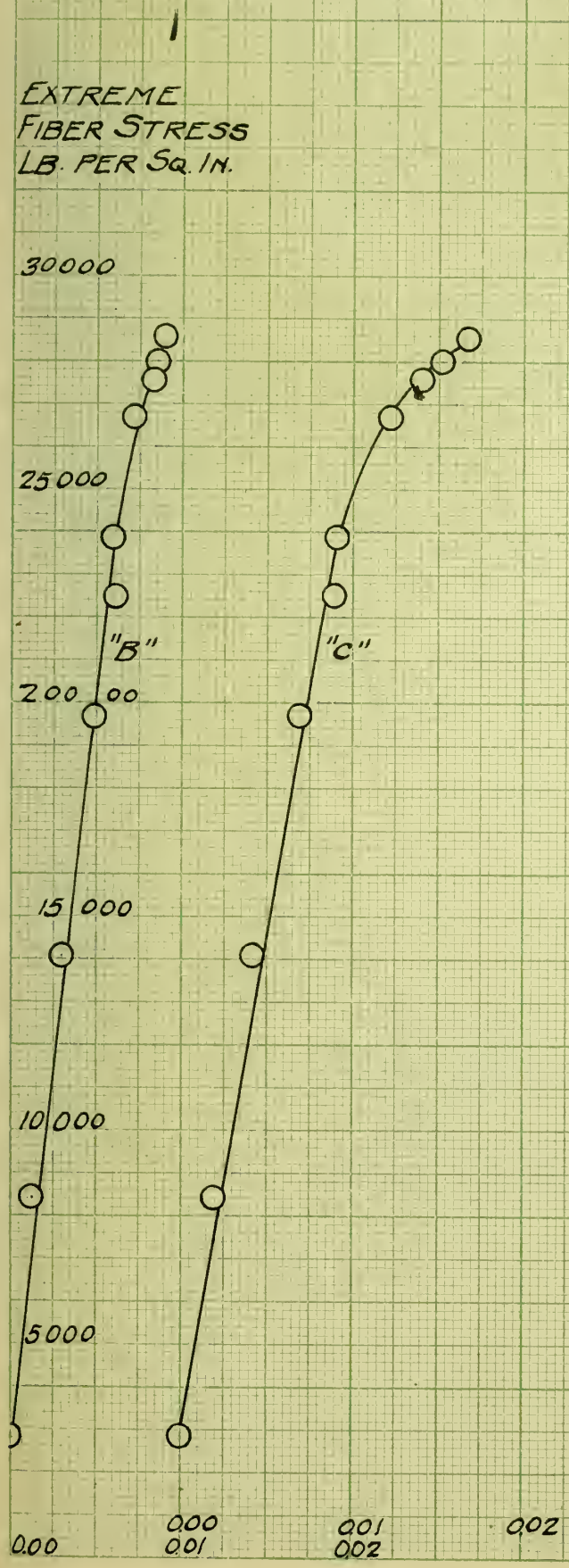
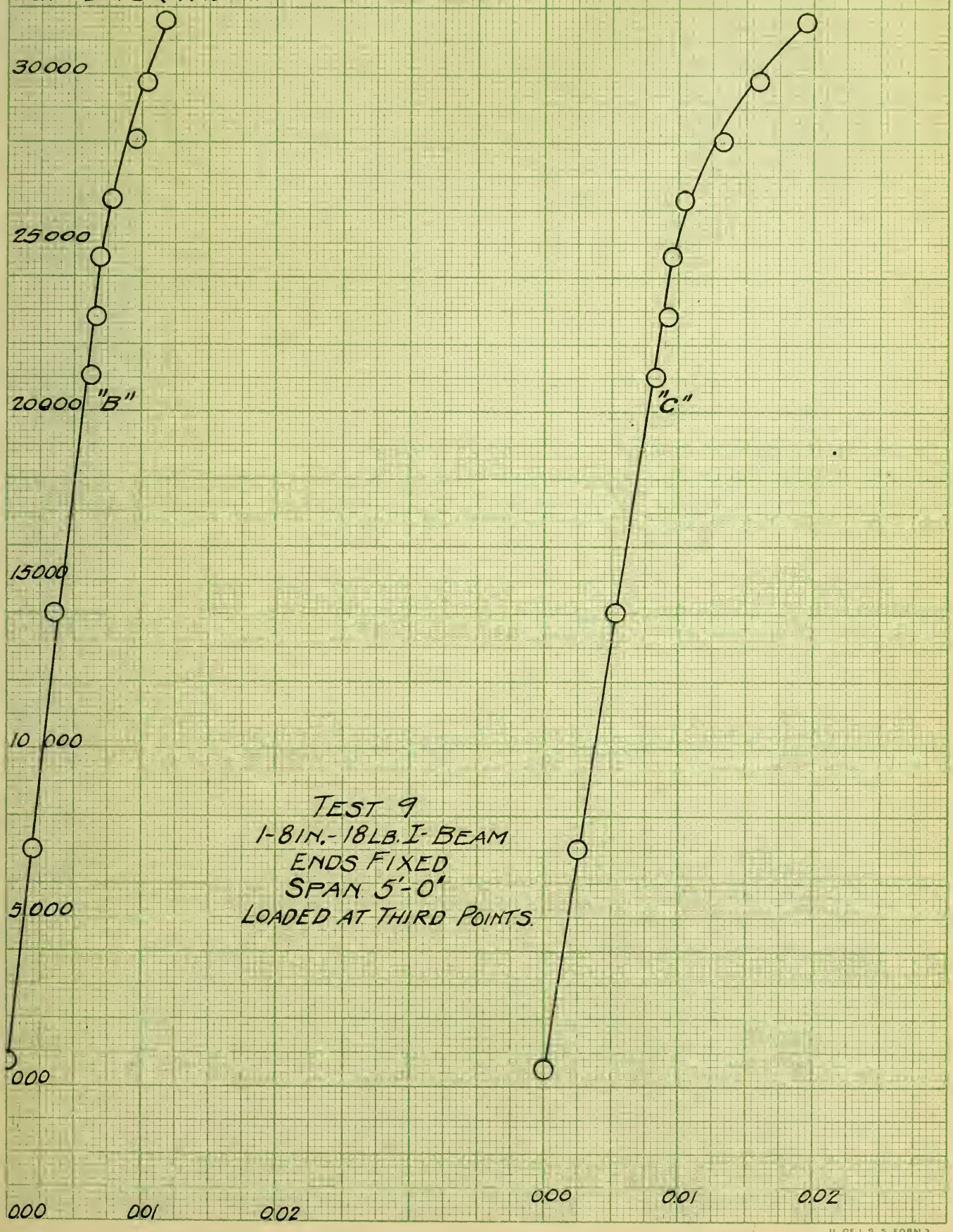
CURVES 20 AND 21.



TEST 7.
1-8 IN.-18 LB. I-BEAM
ENDS FIXED
SPAN 20'-0"
LOADED AT SIXTH POINTS.

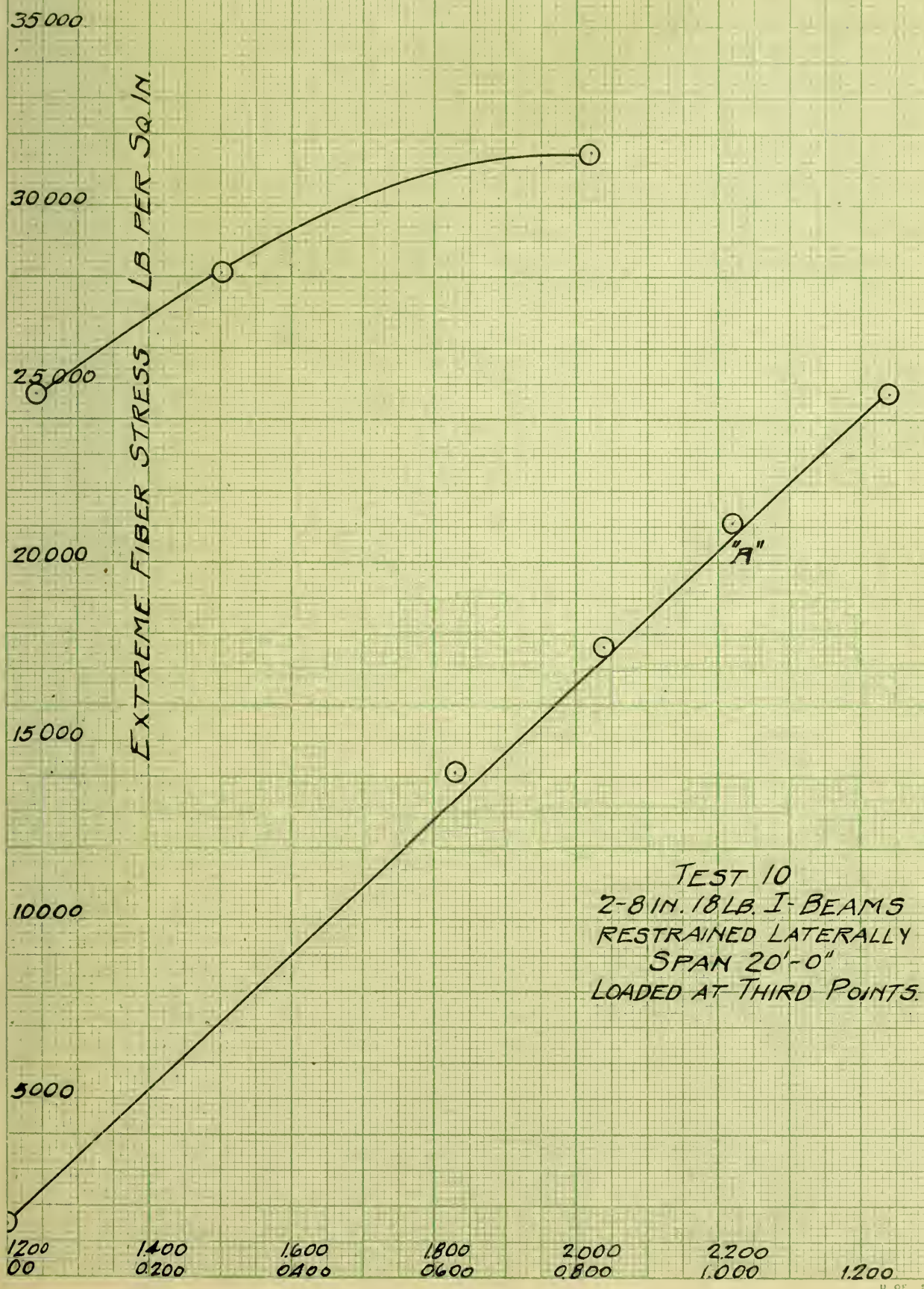
U. CF S. S. FORM 3

CURVES 22 AND 23.

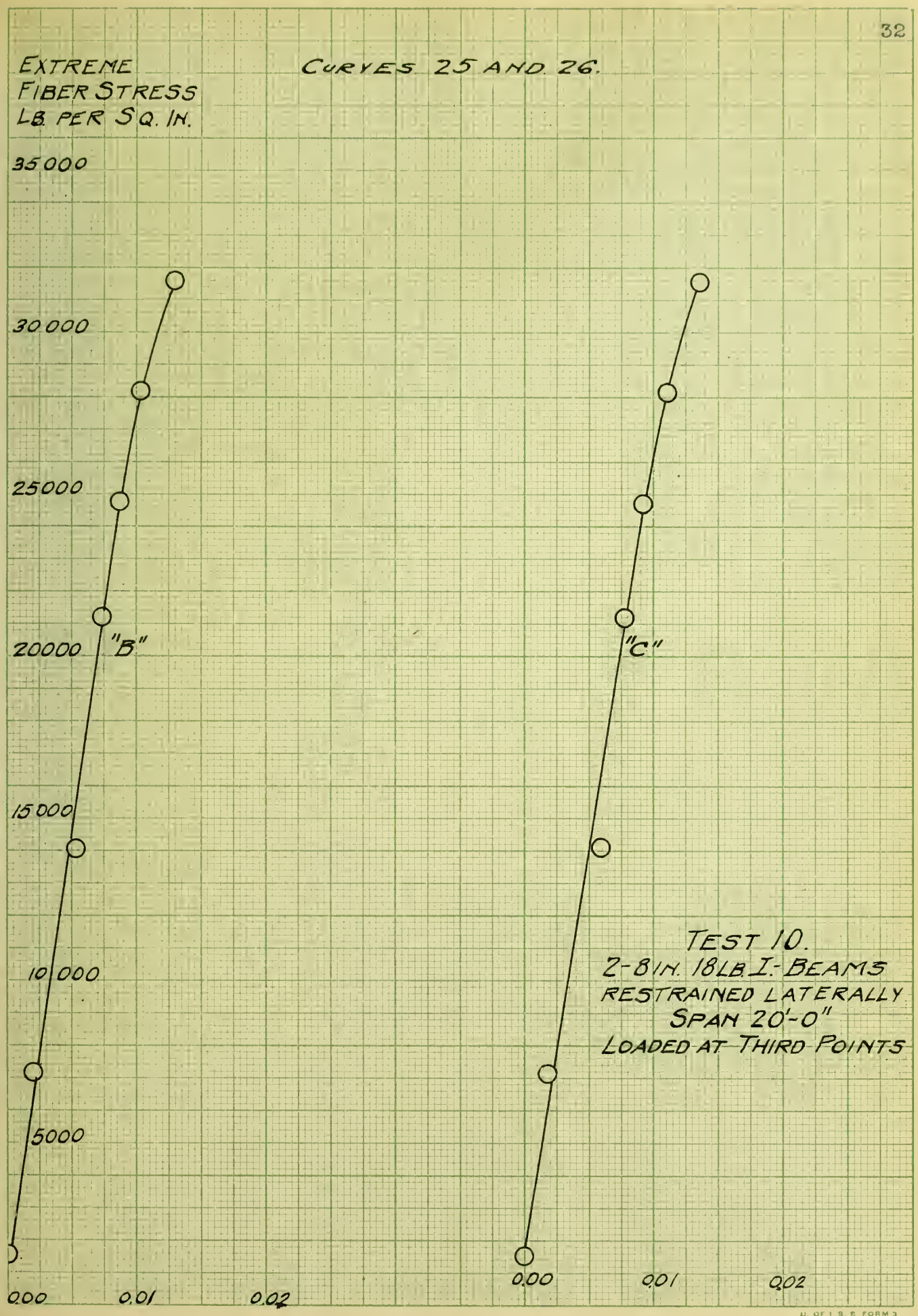


U. OF I. S. S. FORM 3

CURVE 24



U OF S S FORM 3



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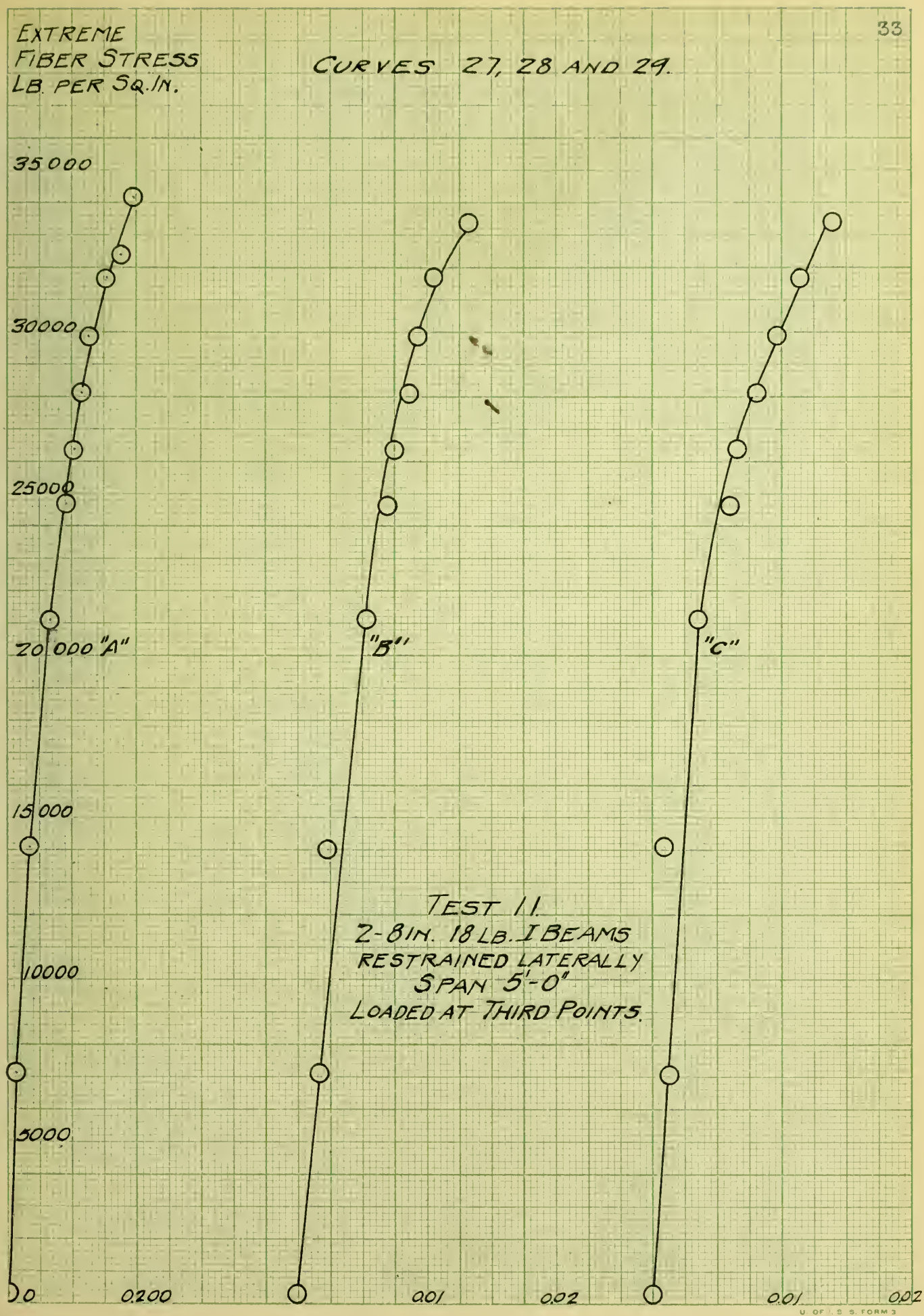

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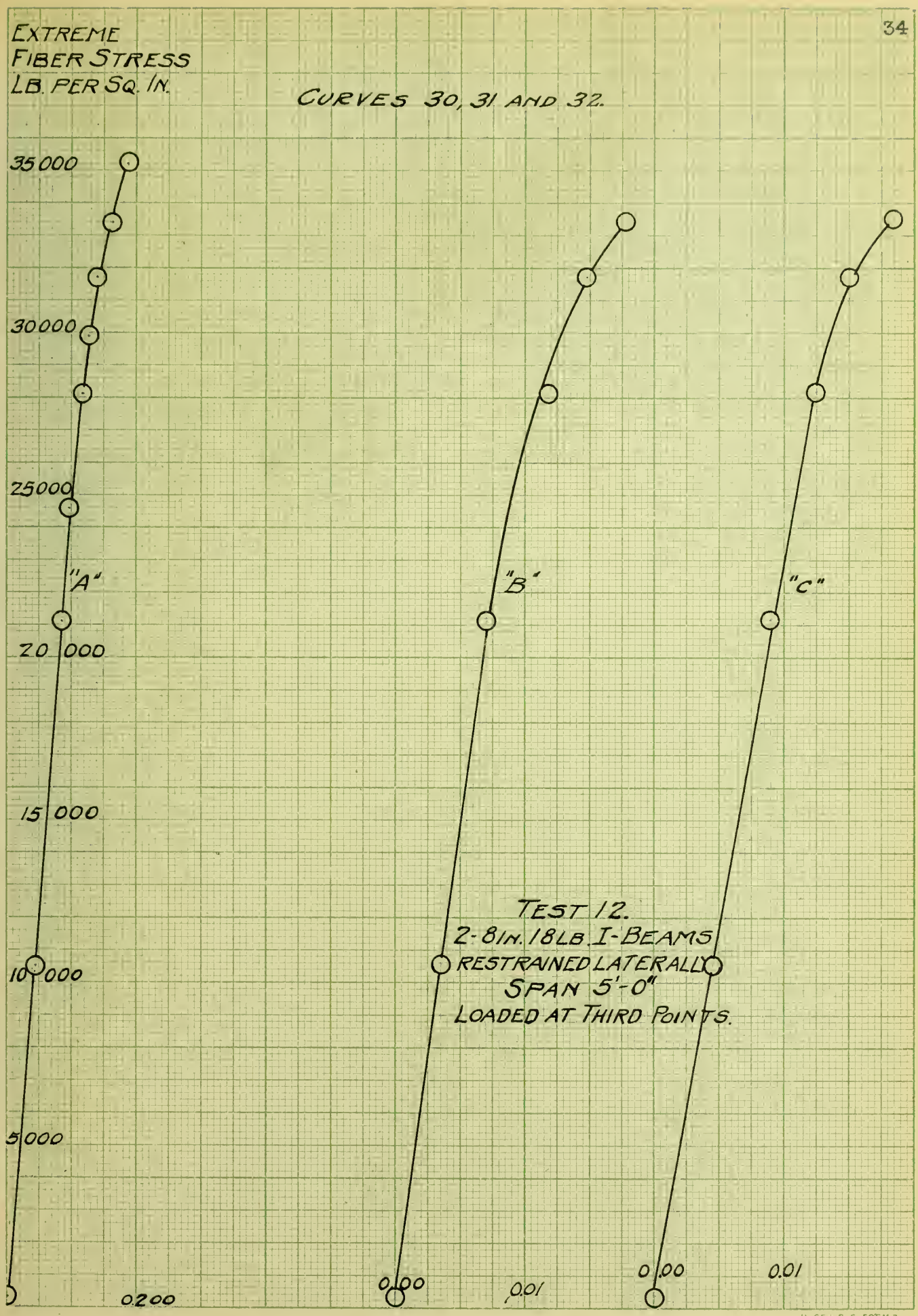

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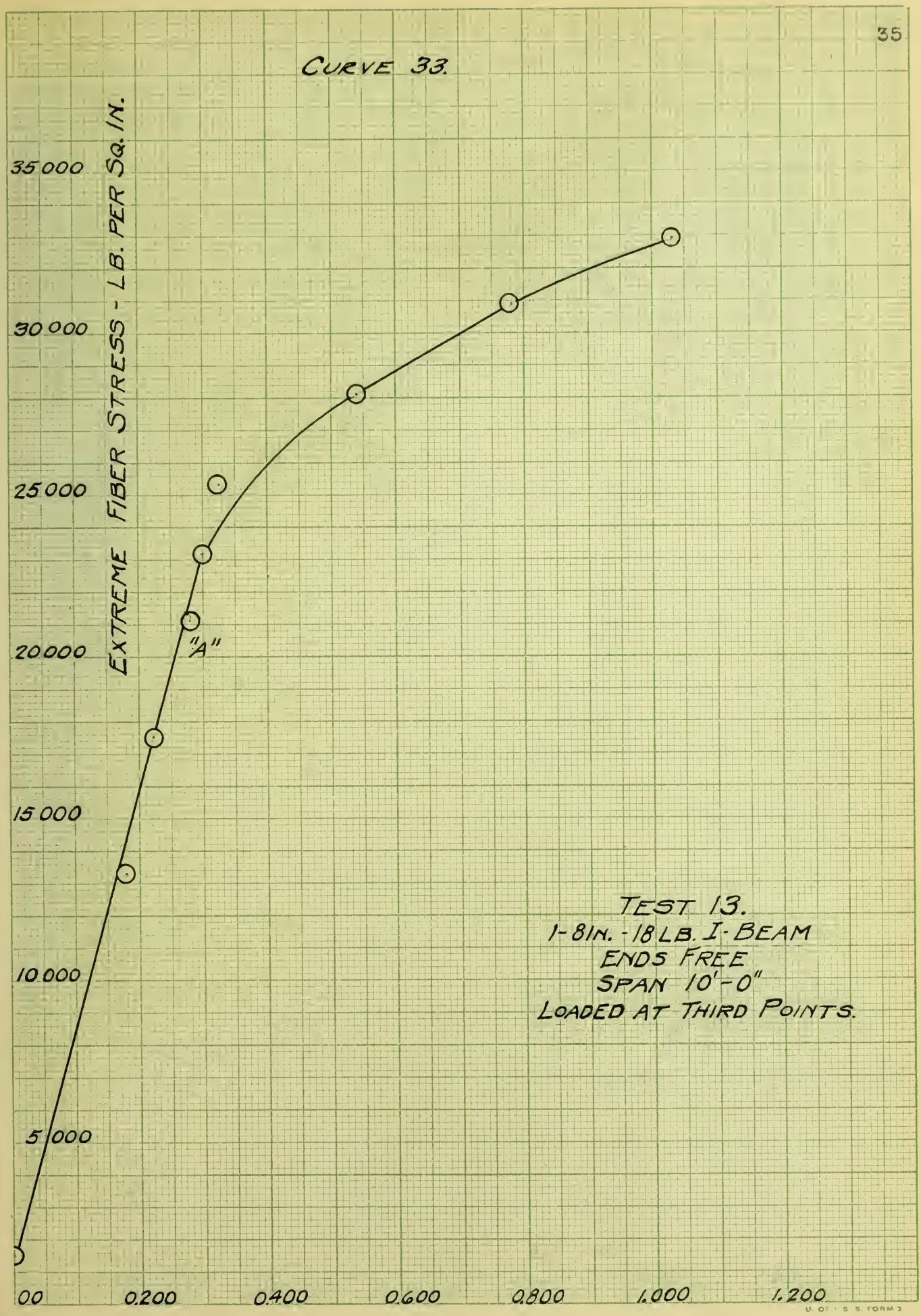

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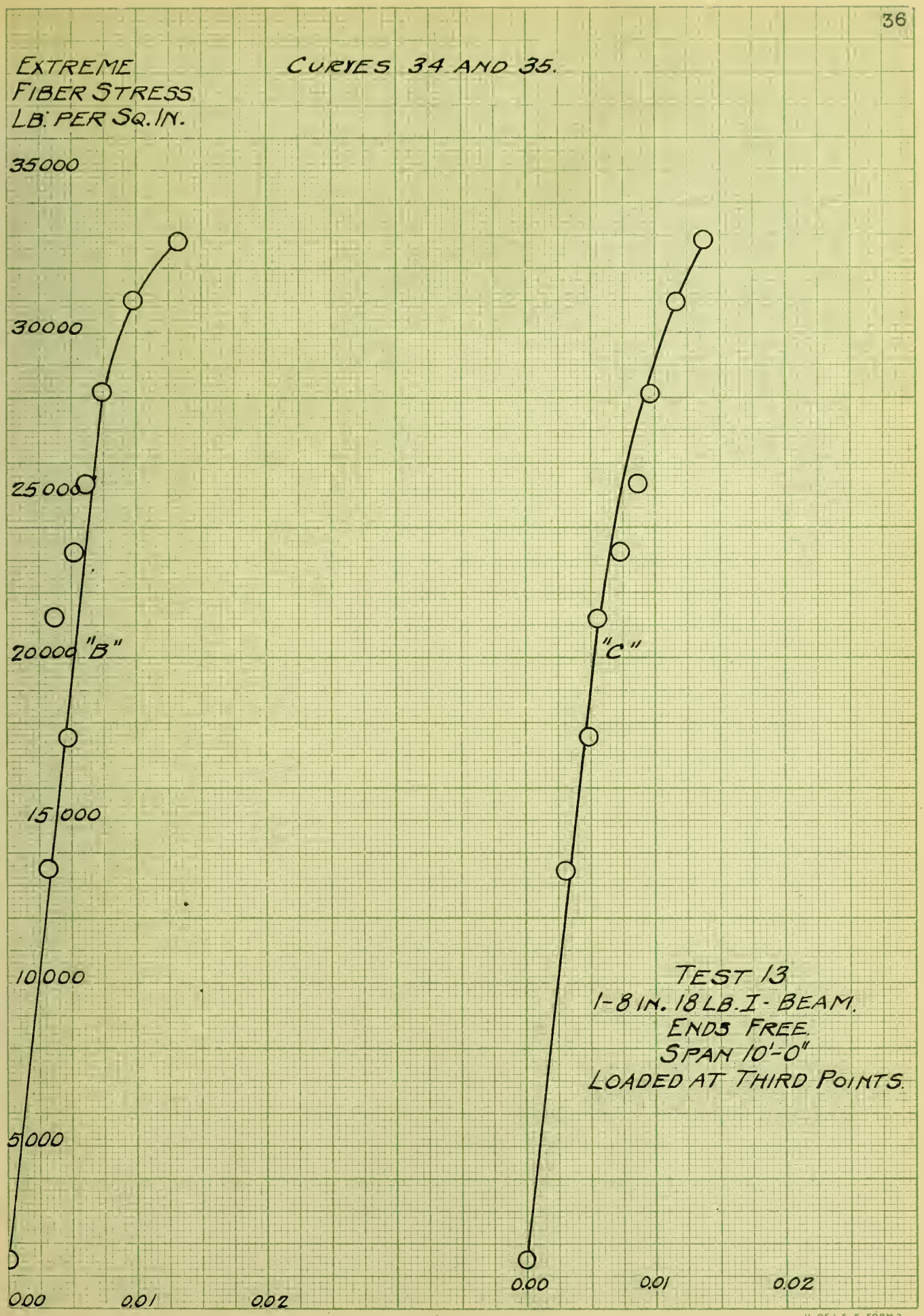
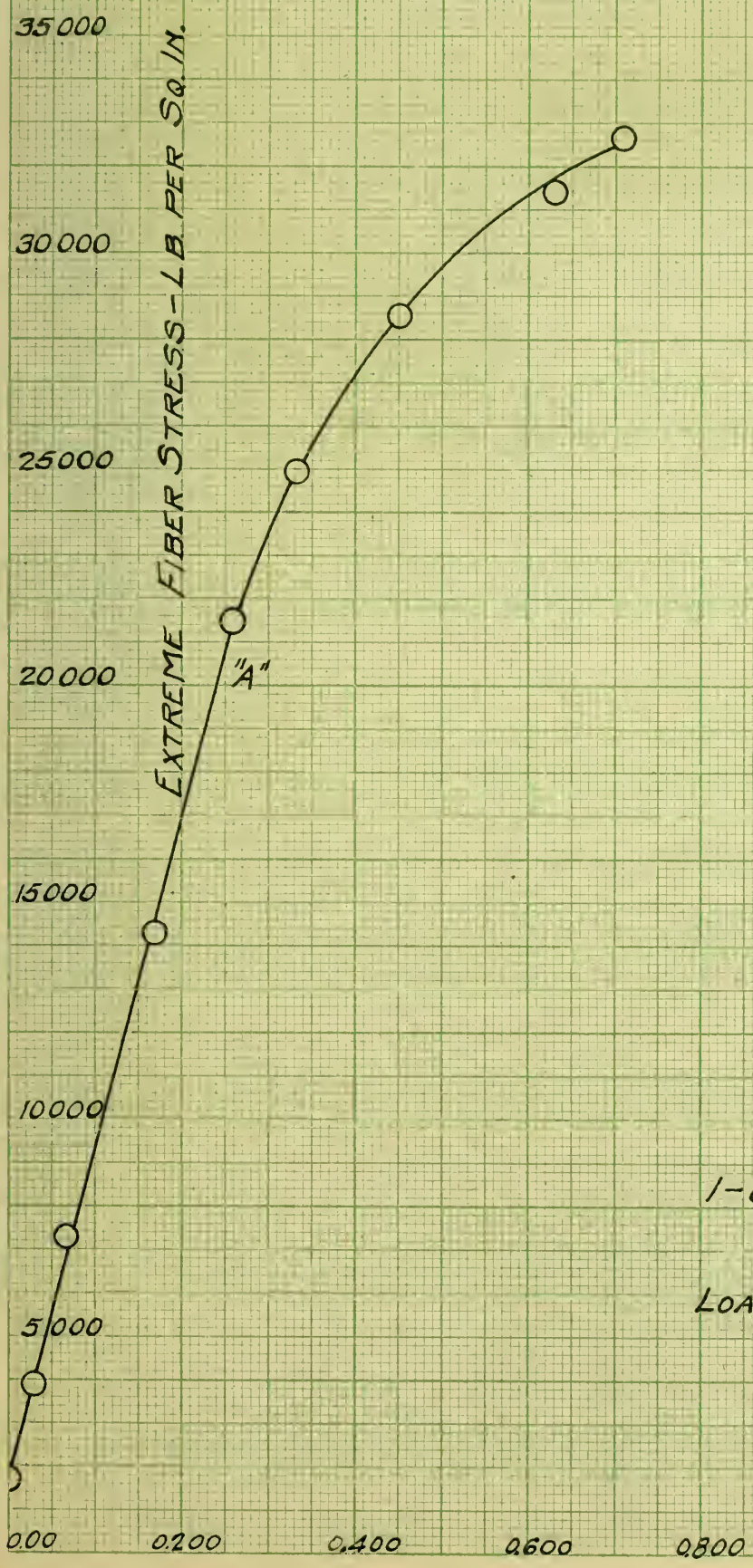


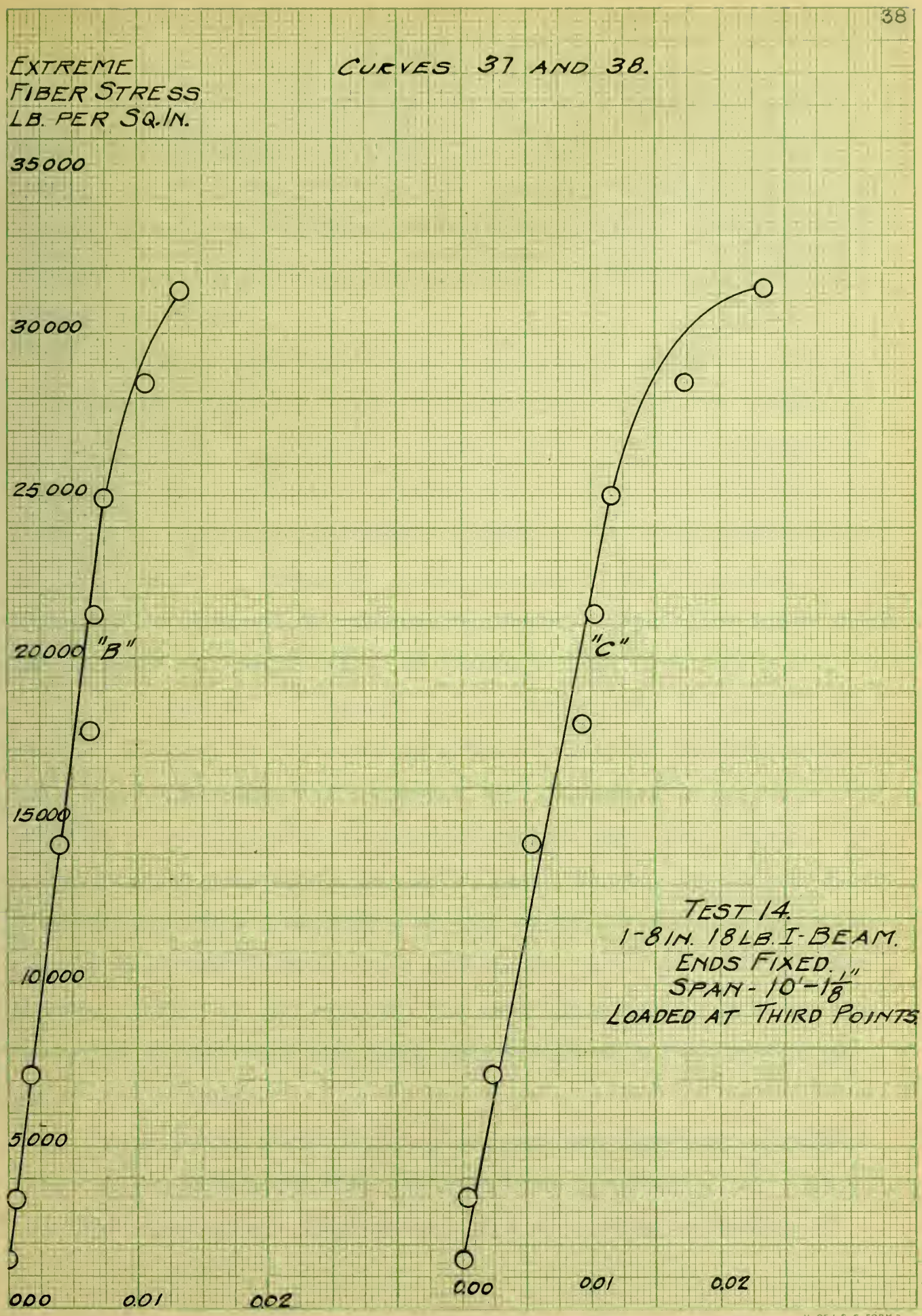
U. OF I. S. S. FORM 3

CURVE 36.



TEST 14.
1-8 IN. - 18 LB. I-BEAM
ENDS FIXED.
SPAN $10'-1\frac{1}{8}$
LOADED AT THIRD POINTS.

U. OF I. S. S FORM 3



U OF I. S. S. FORM 3

DISCUSSION OF RESULTS.

In general, there were two methods of failure, by sidewise buckling and by bending. The former is probably due to one of three causes:- first, eccentricity in the metal due to imperfect rolling; second, stresses due either to eccentric loading or initial internal stresses; and third, lack of homogeneity of the metal of which the flange is composed.

As may be seen from Curves 39 and 40, no appreciable advantage is gained by lateral restraint for short spans; but for lengths up to ten feet, there is a constant increase in the ultimate strength of the beams restrained laterally over those with fixed ends. From this point on, a constant difference in favor of the beams restrained laterally is evident. From this it may be concluded that no appreciable advantage is obtained by restraining beams laterally for spans which have a ratio of span to width of flange of less than thirty.

By referring to Table 2, it is evident that the extreme fiber stress developed by the beams is greatest when the beam is loaded so that the maximum moment is constant over the shortest distance. For example, in beams loaded at the center, third and sixth points, the fiber stresses developed were as follows:- 36,350, 35,350 and 32,870 respectively. This coincides with the results of the investigations made by Professor Marburg. This phenomenon is due to the fact that a greater portion of the beam has the same fiber stress when the beam is loaded at the third and sixth points than when the load is applied at the middle.

From Tables 2 and 4 it may be seen that the yield points of the test specimens cut from the beams are approximately the same for both tension and compression, with an average variation of

0.847 per cent in favor of compression. This is probably due to the different methods of determining the yield point, the autographic diagram being used for compression, while in tension the yield point was determined solely by noting the drop of the testing machine. Further information on the subject may be obtained by referring to Messrs. Caldwell and Dalenberg's thesis for 1911 entitled " Tests of Lacing Bars".

By referring to Tables 2 and 4, it may be seen that the stress developed in the compression flange of short spans at ultimate agrees quite closely with the yield point obtained from the tension specimens. These conclusions agree with those of the thesis of Messrs. Deuchler and Weston, of which this thesis is a continuation.

TABLE III.

DATA FOR CURVES TAKEN FROM EXPERIMENTS.

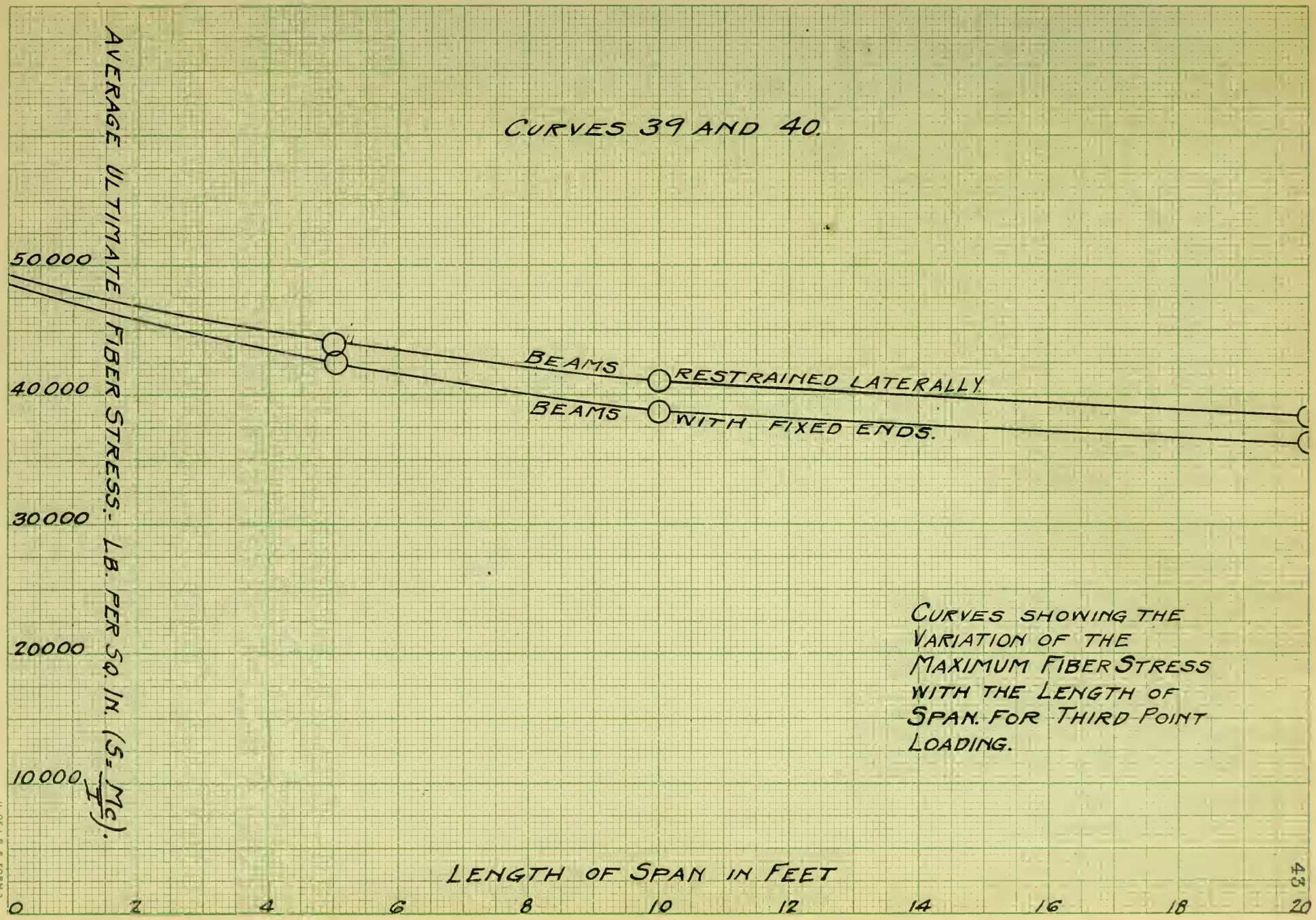
L Length of span, in.	W Width of flange in.	$M_A =$ Average of Max. Stresses developed lb. per sq. in.		$\frac{100 M_A}{M_P}$ M_A expressed in per cent of M_P		$\frac{L}{W}$
		Beams restrained laterally	Beams with fixed ends.	Beams restrained laterally	Beams with fixed ends.	
60	4	43,775	42,500	88.9	87.6	15
120	4	41,100	38,800	83.5	80.2	30
240	4	38,500	36,300	78.3	74.3	60

M_P: Maximum Stress possible.
M_P = 49,250 lb. per sq. in. for beams restrained laterally.
M_P = 48,500 lb. per sq. in. for beams with fixed ends.
See Curves 39 and 40.

TABLE IV.

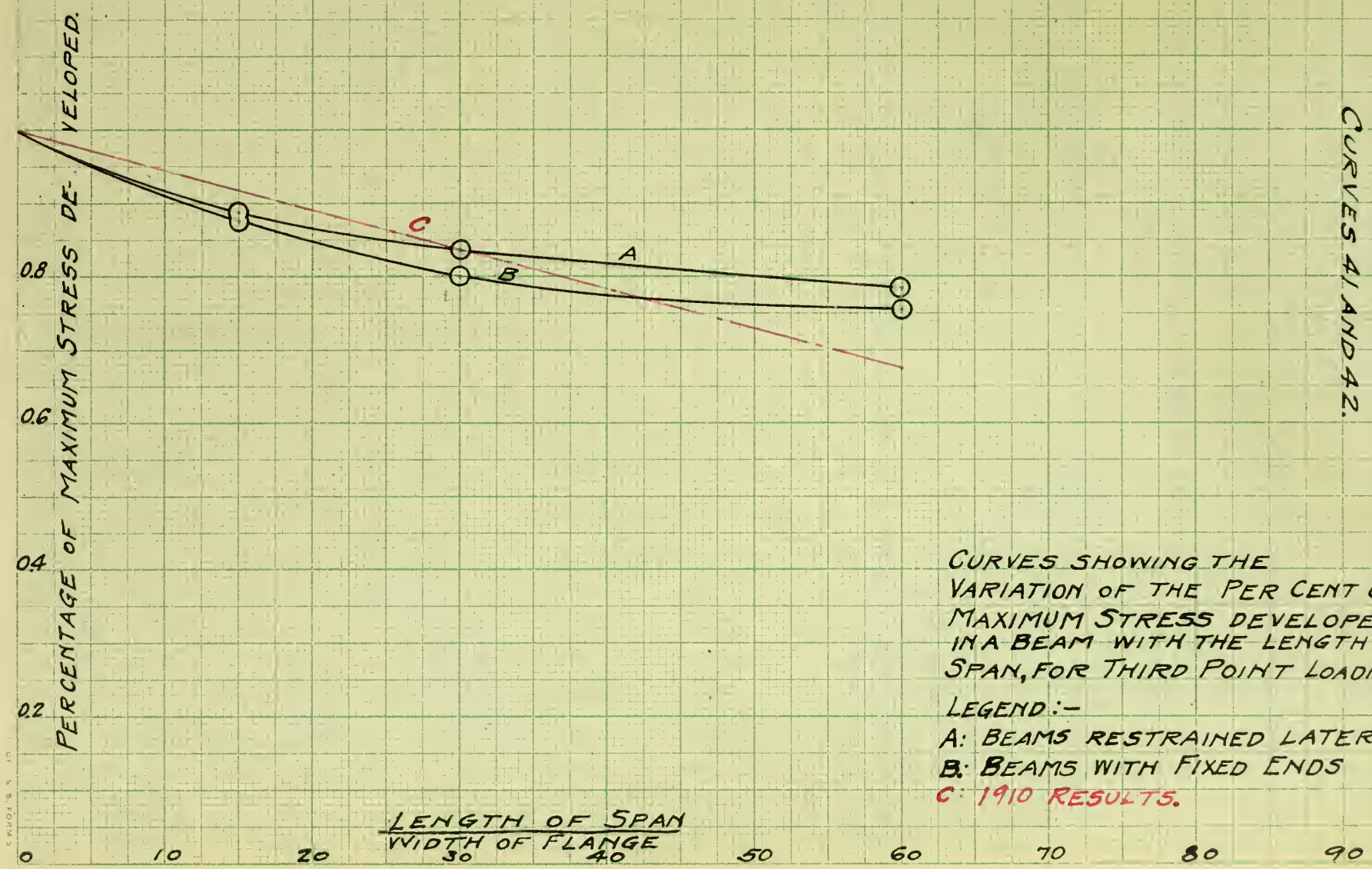
YIELD POINTS AND ULTIMATE STRENGTHS FROM SPECIMEN TESTS.

Test No.	Specimen Marked	Stress - lb. per sq. in			Remarks.	Modulus of Rupture of the Beam in Bending.
		Yield Point		Ultimate		
		Tension	Compression	Tension		
1	1AF	34,730	34,500	60,400	2-8 in. 18 lb. I-Beams connected by batten plates	35,350
1	1BF	33,550	34,710	60,450		35,350
2	2F	32,425	34,600	59,400		36,580
3	3F	34,190	34,365	61,650		37,600
4	4F	34,675	35,025	58,550		32,780
5	5AF	36,275	35,075	60,100	2-8 in. 18 lb. I-Beams connected by batten plates.	36,600
5	5BF	35,475	36,100	60,650		36,600
6	XF	31,650	34550	55,300		29,600
7	6F	33,175	32,580	52,700		29,220
9	6F	33,175	32,580	52,700		35,200
10	1EF	37,960	38,970	65,700	2-8 in. 18 lb. I-Beams connected by batten plates.	36,450
11	and	37,960	38,970	65,700		41,500
12	2EF.	37,960	38,970	65,700		41,500
13	13F	36,250	31,935	61,400		33,800
14	14F	33,700	32,900	62,050.		34,000.



CURVES SHOWING THE VARIATION OF THE MAXIMUM FIBER STRESS WITH THE LENGTH OF SPAN. FOR THIRD POINT LOADING.

U. OF I. B. S. FORM 3



CURVES 41 AND 42.

CURVES SHOWING THE VARIATION OF THE PER CENT OF MAXIMUM STRESS DEVELOPED IN A BEAM WITH THE LENGTH OF SPAN, FOR THIRD POINT LOADING.

LEGEND:-

A: BEAMS RESTRAINED LATERALLY

B: BEAMS WITH FIXED ENDS

C: 1910 RESULTS.

CONCLUSIONS.

From the tests performed and described in this thesis, the following conclusions have been made:-

1.That lateral restraint becomes effective when the ratio of the span to the width of flange is about thirty.

2. That the yield points in tension and compression agree closely.

3. That the maximum computed fiber stress which can be developed by a short beam in the compression flange is about equal to the yield point in tension of the material of the beam.

4. That the maximum fiber stress developed is greatest for that loading for which the bending moment is constant over the shortest distance.

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